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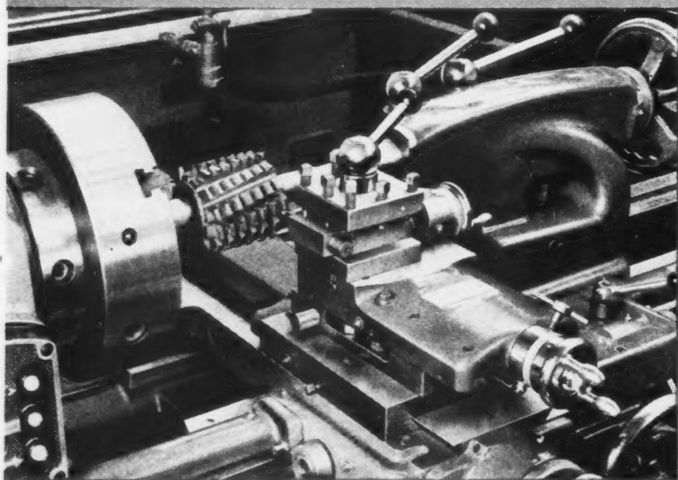

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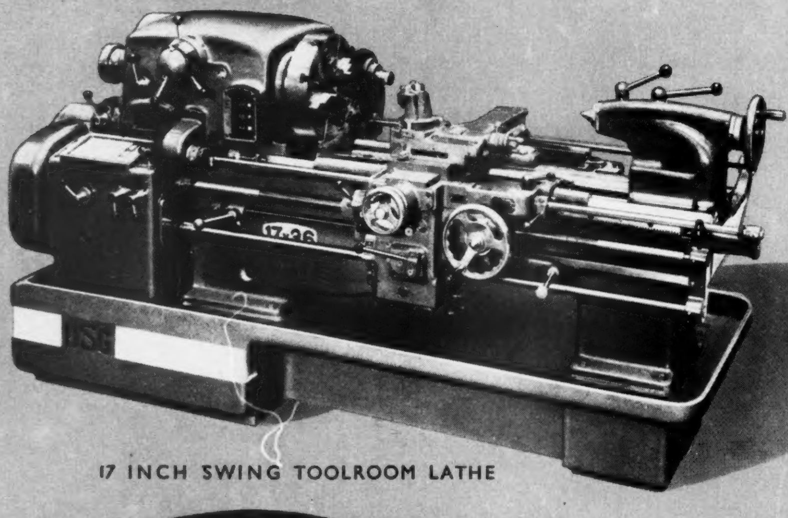

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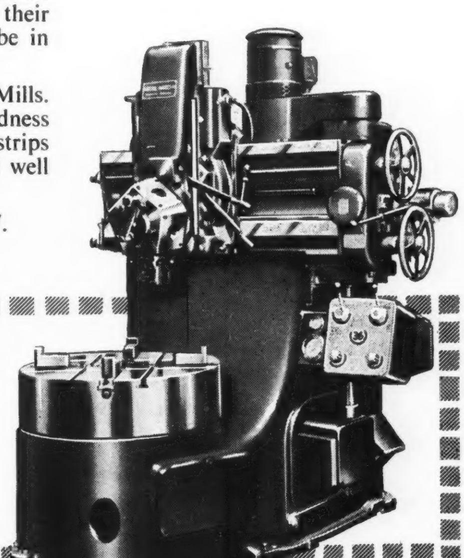

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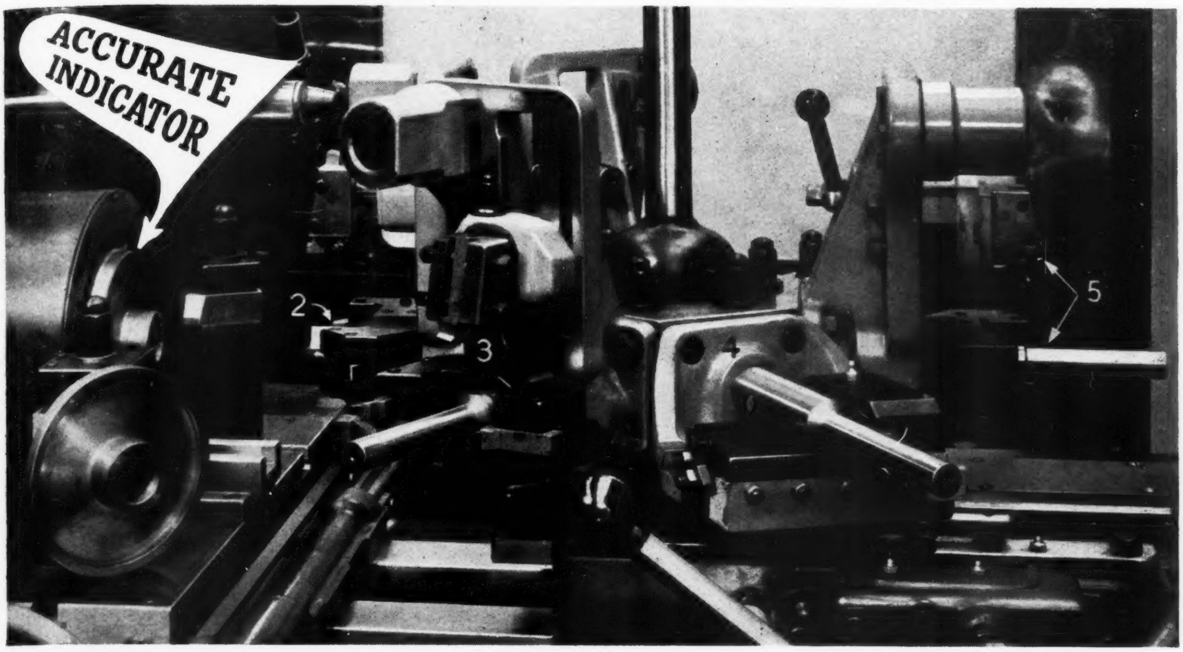

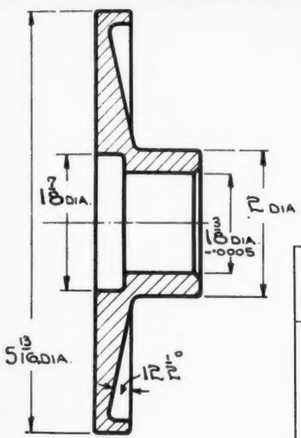

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2. Double Face	—	Rear	260	405	Hand
3. Rough Bore 1⅜", Turn 2" and 5 13/16" dia.	1	—	260	405	125
4. Bore inside Rim and Radius Boss	2	—	358	515	125
5. Turn Boss and Angle Face (2 cuts)	3	Centre	358	515	128
6. Finish Turn o/dia. Face & Chamfer Boss	4	—	358	545	125
7. Reverse Component in Chuck Jaws	—	—			
8. Bore 1⅞" and 1⅜" dias.	5	—	260	405	125
8. Rough and Finish Face	—	Front			128
9. Microbore 1⅜" dia.	6	—	954	343	125
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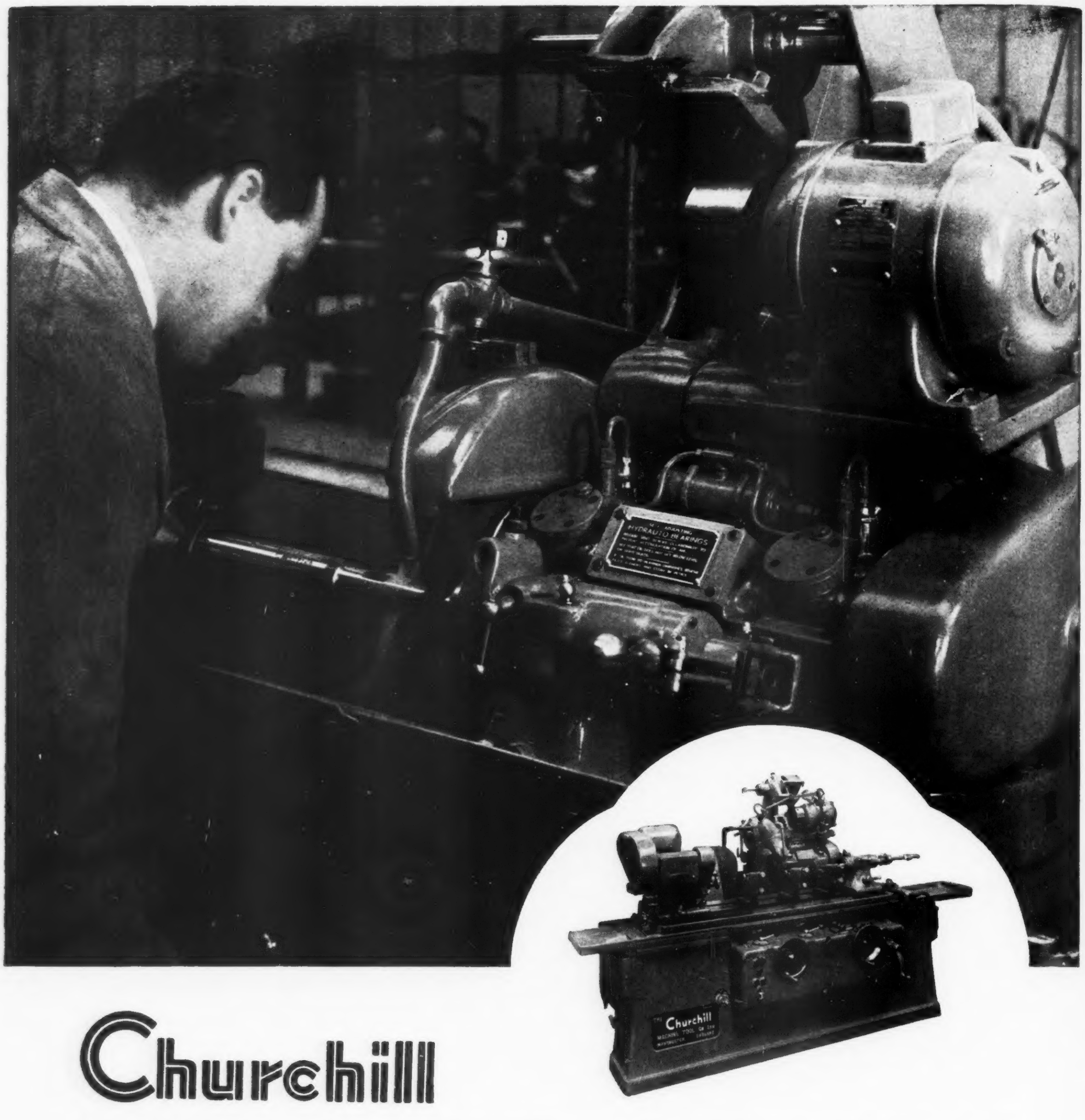

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The Institution of Production Engineers Journal
VOL. 36 NO. 2 FEBRUARY, 1957

The Challenge of the Age

by C. T. BRUNNER.

Director — Marketing, Shell-Mex and B.P. Ltd.

IN the opening article of this series, Mr. E. W. Hancock, M.B.E., President of the Institution, writes of the challenge presented to industry by the increasing tempo of technological change and lays down (rightly, as I believe) some of the conditions of future economic progress.

The widening achievements of science, and in particular such developments as automation, will undoubtedly set a still faster pace in the future and this will have far-reaching effects upon the processes of production and the responsibilities of the production engineer.

Others, no doubt, will have much to say on these topics. I rather welcome this, however, as an opportunity to invite the production engineer to look at processes with which he may be less familiar. For I want to suggest that if the end product is to be a higher standard of living, the assembly line ends not at the works exit but at the point where the product reaches the consumer.

What concerns me is the fact that unless productivity in distribution at least keeps pace in the future with productivity in manufacturing processes, the achievements of the production engineer may be largely nullified. I think it is being widely recognised that the distribution facilities available affect not only the design and quality of the products that can be marketed ; they may determine whether or not a product can be placed upon the market at all. And unless we constantly increase the efficiency of our distributive processes, it means that we are using man-power in distribution which should be directed partly to increasing production and partly to the vital technical training and productive research of which your President speaks.

The business of my Company is marketing. We are responsible for selling in the U.K. market the petroleum products refined in this country or imported from abroad by two major groups in the oil industry : Shell and B.P. We are, therefore, in a position to influence only a small part of the total costs incurred in the long and complex chain of exploration, production, ocean transportation, refining and final distribution to the consumer. Our costs are almost entirely in the field of distribution, but nevertheless we have found that considerable and worthwhile economies can be achieved by consistent study of our organisational structure and the way we do things. Since the War we have, as a Company, undertaken a complete reorganisation and, resulting from this, we are able to claim that productivity has increased to a marked degree, particularly in terms of man-power employed in relation to the volume of trade handled. Over the past six years, the annual tonnage sold by the Company per employee on the payroll has considerably more than doubled.

Our products were formerly distributed from a large number of small local depôts, supplied mainly by rail from larger points situated on the coast and on the main waterways. The effective radius of the old-type depôt was determined largely by the limitations of horse transport. This was a network designed for a situation in which most of our products were imported from abroad in their finished state. With the tremendous post-War development of refineries in Britain a new pattern became necessary, based not on importing points but on the refineries which are now the principal sources of finished products, and taking full advantage of the greatly increased radius of road transportation which is now possible. From the refineries the products are distributed, not to the old network of small depôts but to fewer and larger depôts, each carefully sited and planned. These depôts, wherever possible, are linked to the main sources of supply by water transport.

The new depôts and their equipment are designed to achieve the maximum economies obtainable from large-scale operation. Their storage capacity is greater and can be increased to cover future expansion of trade, layouts are simple, leading to economic manning, and the loading of bulk vehicles has been speeded up by modern loading facilities and the use of meters. For packed products, mechanical handling has been introduced.

In these new depôts, the offices are up-to-date and well equipped and clerical productivity is regularly reviewed. During the past two or three years it has substantially increased, partly as the result of the improvement in working conditions, but mainly because of greater attention paid to organisation and the methods and procedures employed.

Delivery vehicles of greater carrying capacity have been introduced to permit the delivery of larger loads and the maximum use of vehicle time. Larger loads are an important means of achieving economy in distribution. The planning of a delivery schedule in larger loads can substantially benefit both producer and consumer, and for this reason we use every means of encouraging our customers to order in advance and to take large loads.

A Vital Factor

In many operations in distribution, time is a vital factor and this is why we welcome every device we can use for speeding up communication between different points of our organisation. Such devices can sometimes cut out an intermediate process or save an unnecessary journey. In certain jobs, such as the bunkering of ships or the refuelling of aircraft, radio control has made possible the more economic routing of craft and vehicles and increased the speed with which deliveries can be made.

This system of bigger depôts, bigger vehicles, and bigger loads has brought its own problems with it — of bigger responsibilities for our staff throughout the Company. To be able to cope with these problems, staff must be trained. It is no longer enough for them to know their own jobs. Nowadays, with increasing specialisation, it is more difficult for many of them to see where their jobs fit in with those of others. We have, therefore, built up a programme of staff training that includes both technical subjects and those management skills which are becoming increasingly important with the growth of large organisations.

Our residential staff training centre in Hertfordshire has a full programme of courses. Some of these are for new entrants and serve as a general introduction to the Company, while others are for staff with more experience. In these courses, films and contributions by the training staff are used in conjunction with talks by the Company's experts on sales, physical operations and administration, so that current experience and thinking are embodied as far as possible in the instruction given.

A New Pattern of Organisation

To carry out such an extensive programme and to meet the needs of our changing market we have had to abandon many of the old and established ways of thinking. In particular, it was clear that a new pattern of Company organisation would have to be created.

Expansion was foreseen and it was realised that our original pattern of organisation was one that would be outgrown at a relatively early stage.

The new pattern was, therefore, based on two fundamentals: first, decentralisation; and secondly, the 'contracting out' of many of those ancillary matters which can divert the attention and energies of an organisation from its true function, in our case marketing.

Decentralisation is being progressively achieved by the delegation of authority down a short and direct line of command to our geographical 'Divisions' and 'Branches'. The function of Head Office has become largely a 'staff' one of controlling and guiding with specialist advice the line commanders in the field. The principle of contracting out has been successfully applied to many aspects of our business, particularly in the maintenance of motor vehicles and other equipment, and has incidentally made it possible to divert a greater part of available capital to projects directly related to our prime function of marketing petroleum products.

I am aware that this article may have led some production engineers over unfamiliar ground. The essential point that I want to bring out, however, is that it is the same challenge that has to be met by all those responsible, from the

(*continued on page* 88)

THE DEVELOPMENT OF TECHNOLOGICAL EDUCATION IN EUROPE, AMERICA AND ENGLAND

by Dr. B. V. BOWDEN, M.A., M.I.E.E.

Presented to the Institution in Manchester, on 14th November, 1956.

Dr. Bowden was appointed Principal of the College of Technology (now the College of Science and Technology) in 1953. He had previously spent three years with the Ferranti company, introducing digital computers to the English market.

Throughout the Second World War, he was engaged in radar research, and immediately after the War, he joined the firm of Sir Robert Watson Watt and Partners, Consulting Engineers.

From 1931 to 1934, Dr. Bowden worked in Cambridge, in association with Lord Rutherford.

IT is astonishing how slow we have been in this country to follow the advice and heed the warnings of our great men. In 1570 Sir Humphrey Gilbert tried to found an academy where men could "try out the secrets of nature." He said that "there should be no gentleman in England but is good for somewhat, whereas now the best part of them are good for nothing." He admonished his countrymen to eschew foreign luxuries and to exploit their craftsmanship. Sir Francis Bacon found it strange that "all the Colleges are dedicated to the professions (Law, Medicine, and the Church) and none to the Arts and Sciences at large . . . It is esteemed," he said, "a kind of dishonour to learning to descend into an enquiry upon matters mechanical." He tried to establish a great institution (to be called Salomons House) for the advancement of science and technology; he insisted that the purpose of knowledge should be to gain "power over nature", though the universities obstinately ignored the application of science to ordinary life. Had it not been for the outbreak of the Civil War, the Government might have founded some such institution, and created a university in Manchester. If King Charles the First had not lost his head, there might have been a technological institution in Manchester 300 years ago.

Throughout the 18th century English universities became completely detached from practical affairs; they confined themselves almost entirely to the study of ancient texts and only 16,000 students went to Cambridge in the whole of the 18th century—less than half as many as had been there in the preceding 100 years for, as a contemporary remarked "intelligent persons could not fail to observe that the subjects to which their attention was directed had no relation to any profession or employment whatever, and that the discussions connected with them had no analogy to those trains of thinking that prevailed in the ordinary intercourse of society".

After Newton left Cambridge the study of mathematics in the university was sadly neglected. When Thomas Young went up in 1798 after some years in Göttingen he was "ashamed to find how much the foreign mathematicians have surpassed the English in the higher branches of the sciences". Ten years later Babbage found, as a self-taught undergraduate, that he knew more algebra than his tutor.

In Oxford the classical authors were unchallenged; Aristotle reigned supreme in philosophy, science was entirely neglected, and the exercises and examinations wore all the appearance of a solemn farce.

"In the universities" wrote Adam Smith in *The Wealth of Nations,* "the youth are neither taught, nor always can find proper means of being taught, the sciences which it is the business of those incorporated bodies to teach". No wonder Hobbes felt impelled to say "If I had read as much as other men, I should have known no more than other men"; and that Gibbon should have regarded his university career as the most idle and unprofitable period of his life.

The First Chair of Chemistry

Cambridge University appointed its first Professor of Chemistry as long ago as 1702; this was the first Chair of Chemistry in England and it was awarded (without a stipend) to an itinerant lecturer who had been giving courses in the university for some years. His laboratory was a small room in Trinity College, but his successor had to work in a room that had been abandoned by the University Printer in 1716 and that "was of no use to the University for any other purpose". One can assess the importance that the university attached to experimental science in those days from the career of Richard Watson, who became Professor of Chemistry at the age of 27 in the year 1760. He said when he was appointed that he knew nothing at all of chemistry and had never read a syllable on the subject nor seen a single experiment in it. He sent to Paris for an "Operator" and studied for a year before he felt qualified to lecture, but his most important achievement was to persuade the authorities to give him a salary of £100 a year. After seven years as Professor of Chemistry, Watson was translated to the Regius Chair of Divinity. He afterwards became Bishop of Llandaff and made a considerable fortune from a new method of manufacturing gunpowder.*

We may smile at our ancestors, but only 20 years ago Bertrand Russell attributed the bitterness and cynicism of many university students to their "consciousness that their work had no real importance", and an Oxford Don found that "many thoughtful undergraduates are growing very weary of pursuing half-heartedly a course of study that they know to be none too good, and vaguely attempting to supplement it with occasional gems picked up from the side-shows".

If one were to judge the university courses in engineering in England 30 or 40 years ago by the comments of some of the most successful engineers in this district to-day, one might almost believe that the universities had been little more use to them than Oxford was to Gibbon. It would be a mistake to assume too confidently that they are all above criticism today.

* The Cock Inn in the village where Watson was born was rechristened "The Bishop of Llandaff" in his honour. A neighbouring publican adopted the name of the "Cock" and indignant local pride was responsible for the notice which was so famous in the Lake District for many years. "*The Bishop of Llandaff is the real old Cock.*"

Despite the indifference of the old universities, many Englishmen made great efforts to encourage science and the new learning. Several learned societies were founded, the most famous of which is, of course, the Royal Society of London, which originated in the meetings of Gresham College. The Lunar Society of Birmingham was frequented by Boulton and Watt, Wedgwood and Erasmus Darwin, who defined a fool as "a man who has never done an experiment in his life". The Royal Society of Arts played a most important role in developing science and agriculture and was patronised by merchants, manufacturers and nobility alike. When Dr. Johnson tried to speak there, he found that the company was so distinguished that all his flowers of oratory forsook him.

Because the universities refused to admit students who were not members of the Church of England, the Dissenters (particularly the Quakers) established several academies; most of them have long since been forgotten, but they provided education of the highest standard at a time when the English universities were nearly as palsy-stricken as the Church.

In the academies the terms were longer and the syllabus of lectures was much heavier than at Oxford or Cambridge. None of the academies neglected science. During the latter half of the 18th century and the whole of the 19th century, a man had about 30 times more chance of being elected to the Royal Society if he were a Quaker or of Quaker descent than if he belonged to the general population. That great chemist Joseph Priestley taught in Warrington Academy (near Manchester) which became known as the Athens of the North; for 30 years or more it exerted a greater influence than either of the old universities. Priestley was in Warrington when Richard Watson was Professor in Cambridge.

The Manchester Literary and Philosophical Society was founded in 1781 by Dr. Percival who had been the first student to enrol in Warrington Academy. Later in life he helped to establish a College of Arts and Science in Manchester. John Dalton taught in the Dissenters' Academy in Mosley Street, Manchester, and was very closely associated with our own Mechanics' Institute; he was President of the Manchester "Lit and Phil" for many years. The Society played a most notable part in promoting both science and technology and did so by bringing them and their exponents together. Joule, who discovered and measured the mechanical equivalent of heat, was a member of the Society; so were Roscoe and Robert Owen (the father of English Socialism) as well as Playfair and Calvert, both of whom became famous as chemists before they made their fortunes in industry.

Science Teaching in America

Other frustrated Englishmen tried to develop the teaching of science in America during the 18th and 19th centuries, and endowed professional chairs at Harvard and Yale. The largest "bevatron" in the world to-day is in Berkeley, a city in California which owes its name to an English bishop, who tried

in 1730 to found an enlightened university in America to do what the old establishments had failed to do in this country.

The English public schools, like the universities, were slow to shake off the traditions of the Middle Ages; apparently some of them have failed even yet to realise that it can be more important for a schoolboy to understand something about the tools of modern industry than it is for him to learn about Jupiter's love-life, or to study the properties of Greek and Latin verbs which, to the delight of the pedagogue, are irregular to the point of impropriety in their behaviour.

This extraordinary failure of our educational system led to a most extraordinary result. The industrial revolution made this country rich and great; the technological developments that were responsible for it are our greatest national contribution to the wealth and welfare of mankind, but it was made almost entirely by self-taught men, by Dissenters who were kept out of the universities by statute, and by students who had been to private academies. For nearly 100 years the most important technological developments in this country were made quite independently of the universities and sometimes in the teeth of hostility from both University and Church.

Attitude of the Ruling Classes

Jane Austen's novels show how the ruling classes despised and ignored the industrialists and merchants whose efforts had produced the wealth upon which the whole country depended. Educated men apparently thought that inventive genius and technological progress were bound to happen quite naturally in England, and that it was right and proper that the gentry should profit by them and qualify themselves to do so by studying the literature of ancient Rome. "In England," wrote Babbage about 1830, "those who have hitherto pursued science have had no very reasonable ground for complaint, for they should have realised that there was no demand for it, and that it led to little honour, and less profit. It is lamentable that a country, eminently distinguished for its mechanical and manufacturing ingenuity, should be indifferent to the progress of inquiries which form the highest departments of that knowledge on whose more elementary truths its wealth and rank depend."

The industrial north was then in an intellectual ferment; skill and productivity in manufacture increased faster than they had ever increased before in the history of the world. In less than a century an area about 50 miles in radius centred on Manchester became the workshop of the world, but the official educational system of the country remained sunk in complete stagnation or devoted itself to those sophisticated intellectual exercises which produced the Oxford Movement*.

In 1824 half a dozen Manchester business men founded the Mechanics' Institute from which our College has grown; 30 years later John Owen founded the University of Manchester in Richard Cobden's house in Quay Street.

But what has been happening abroad in the 18th and 19th centuries? Other countries were envious of the prosperity the Industrial Revolution brought to us, and were determined to overtake us. They had already improved the quality of instruction in their universities and schools; these were to be the instruments of enlightenment. Germany took the lead in introducing science into her universities; our own King George II founded the University of Göttingen in 1734 and from the first it had a flourishing Faculty of Science. Several other modern universities were founded at about the same time in other parts of Germany.

Although the Continental universities accepted science readily enough, many of them were unwilling to teach technology. Continental governments refused to be influenced by academic prejudices against the subject and so they founded a series of special institutions to perform the vital functions for which the universities had refused to make themselves responsible.

Technological institutions were founded in Brunswick in 1745, in Freiberg in 1756 and in Clausthal in 1775; these were really superior "craft schools", and the first technological institution of university rank was the Ecole Polytechnique, which the National Convention had to establish in Paris in 1794 because the French universities were devoting themselves at that time exclusively to library and abstract studies. Ever since then "Polytechnicians" have dominated French industry and much of the civil service.

The Technische Hochschule in Berlin was founded in 1799; the School of Structural and Civil Engineering, which was the first part to open, undertook the practical and theoretical training of surveyors and engineers. The curriculum taught there in 1800 includes many subjects that are studied in a modern school of civil engineering. Some of the leading engineers in Germany were appointed to the staff of the College, for the authorities knew that unless they had adequate scientific knowledge the students of the Hochschule would not be engineers at all, but only craftsmen; moreover, the Prussian Government founded a Trade School of Crafts and Professions in 1821, so that the Hochschule could concentrate entirely on advanced work. Nevertheless, the University of Berlin would not admit engineering to its curriculum because the other faculties considered that it was "non-scientific". In 1875 the Hochschule was granted a Charter and it then amalgamated with the old "trade school", which had ceased to concern itself with elementary work. This great institution achieved complete equality with the other German universities before the end of the century. In 1930 it had 4,500 students and there were then more than 22,000 full-time students in the other Technische Hochschulen in Germany. There were about 4,500 university students of technology in this country in 1930.

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* "A knowledge of education is the common property of civilised Europeans with the exception of the Southern English, and the English Governing Class"—
Sir William Mather.

Technical Universities

Much confusion and some difficulty have been caused in England by the popular misconception that the Technische Hochschulen can be described as "Technical High Schools". They are in fact, as we shall see, Technological Universities of a type which does not exist in this country. In America they are usually called "Institutes of Technology". The distinction between a "Hochschule" and a "Universiteit" has nothing to do with technology as such — there are Hochschulen for agriculture and economics, for example. The institutions have the same intellectual standards and may be the same size. A "Hochschule" has less than four Faculties, a "Universiteit" must have four or more.

When the Great Exhibition of 1851 showed this country what foreign industry could do, we had to realise that we no longer had a virtual monopoly of skill in manufacture, although the superior ability of our engineers and craftsmen was still complacently taken for granted; many of our industrialists learned for the first time that they would have to meet strong competition from abroad. German and American engineers were available in large numbers and it was plain that "no further triumphs awaited mere vigour undirected by knowledge".

Introduction of Reforms

The University Commission of 1850 began the very necessary reforms of our educational system. Oxford and Cambridge were slowly recovering from the intellectual ebb of the previous century; less than 400 students matriculated in either University that year and the only other university education to be found in England was in the two Colleges in London and one in Durham. Mathematics in Cambridge was triumphantly resurgent, but it was not until 1861 that undergraduates were able to take the National Science Tripos, and the University had no laboratory for the experimental study of physical science until the Cavendish Laboratory was opened in 1874 by James Clerk Maxwell *.

The anxiety of our industrialists and the enterprise of the Prince Consort led to the suggestion that an Industrial University should be founded in this country; the profits of the Great Exhibition were used to buy those estates in Kensington where the Imperial College now stands. The Trustees were required "to increase the means of industrial education, and to extend the influence of science and art upon productive industry".

Nevertheless, despite all that the Prince and the Commission could do, other countries were still progressing much faster than we were.

There were six Universities in Holland, most of which had Faculties of Science, but the University of Amsterdam refused to teach Engineering or even to admit that it was a subject which could properly be taught at university level elsewhere, so the Government of the Netherlands founded a Technische Hochschule in 1870 in Delft to provide courses in science and technology. The institution achieved "university status" in 1905, and it received a new Royal Charter in August, 1956. There are now more than 5,000 students in Delft, but despite a magnificent building programme which has been undertaken since the end of the war, it is so overcrowded that another Technische Hochschule is to be established in Eindhoven next year, in order to help to educate about 11,000,000 Dutchmen.

The Technische Hochschule in Zurich was founded in 1855. It now has 2,700 undergraduates; about as many as the Imperial College, London, Manchester College of Science and Technology and the Royal Technical College, Glasgow, put together. The population of Switzerland is only 5,000,000 — about as many people live within 25 miles of Manchester, yet there are half a dozen universities in Switzerland, most of them have flourishing faculties of science; the great school in Zurich concerns itself with both science and technology[1]. The skill of their engineers has enabled the Swiss to achieve a standard of living which is second to none in Europe.

The early American settlers attached great importance to university education. At the beginning of the American War of Independence there were nine universities in the States; we then had two, and we had to wait for an American to found the Royal Institution "to facilitate the general introduction of useful mechanical inventions and improvements and teach the applications of science to the common purposes of life". The Federal American Government granted land to endow a university in each state and expected in return that these institutions would play their proper part in the development of the techniques upon which the prosperity of the country depended. Most American universities (as distinct from their Liberal Arts Colleges) have engineering schools. Nevertheless the Americans were influenced by developments in Europe and they established several special institutes of technology, of which the most famous was founded in 1861 by Barton Rogers in Cambridge, Massachusetts[2]. There were 1,200 students there by the turn of the century. In 1951 M.I.T. had 3,000 undergraduates and 2,000 postgraduate students. In the same year (1951) only 270 postgraduate degrees were awarded in the whole of England in all branches of technology.

The Most Serious Struggle

The lessons of the 1851 Exhibition were driven home yet again at the Great Exhibition in Paris in 1867; the English exhibits were described as "slovenly intruded heaps of raw materials mingled with pieces of rusty iron". Many Englishmen then began to be seriously alarmed and in 1878 Thomas Henry Huxley wrote "We are entering now upon the most serious struggle for existence to which this country was ever committed. The latter years of the

* Members of Senate maintained that because many university lecturers were ordained clergy of the Church of England, it would be impious of undergraduates to demand experimental verification of the theory they learnt in their classes.

[1] Einstein was a lecturer in Physics in Zurich when he announced his Theory of Relativity.

[2] Rogers knew and admired the Mechanics Institute in Manchester; he called his new foundation Massachusetts Institute of Technology.

century promise to see us in industrial war of far more serious import than the military wars of its opening years. To those of us who remember the cotton famine and reflect how much more serious a customer famine could be, the situation appears grave."

There were then 25,000 university students in Germany ; we had only a fifth as many. Several more Hochschulen were founded in the '70's and educated Germans reached China in large numbers. Liebig remarked that "Everywhere but in England it is regarded as necessary to incorporate science into university courses." The German Government subsidised research in the Hochschulen, in universities and in industry ; long before the end of the 19th century the Germans led the world both in chemistry and in the manufacture of precision optical equipment, despite the fact that aniline dyes were discovered in England in the '50's, and John Dolland had made achromatic telescopes for the Duke of Wellington. The manufacture of organic dyes in this country was a flourishing industry for a few decades, but it declined and almost disappeared because British scientists and technologists showed no interest either in the technology of dyestuffs or in teaching and research in organic chemistry.* Huxley was familiar with the first of that melancholy series of scientific ideas which originated in this country and were brought to fruition abroad.

An Unsuccessful Attempt

To remedy this deplorable situation, John Scott Russell tried unsuccessfully in the '70's to persuade Mr. Gladstone to found a National University for Industrial and Scientific Training. Russell himself was an outstanding example of the academic turned engineer. He was Professor of Physics at 24 ; he then became an ironmaster and built the *Great Eastern.* He had graduated in Scotland — in those days the Scottish Universities were far more enterprising than ours. Mr. Gladstone once declared that poverty was no concern of the House of Commons, so he could not have been expected to understand and sympathise with demands for expensive new facilities for technological education. Mr. Gladstone did nothing, and the prebendary of Durham obviously spoke for many of his countrymen when he remarked complacently that "the advantages of a classical education are two-fold ; it enables us to look with contempt upon those who have not shared its advantages, and it fits us for places of emolument, both in this world and in the next".

At the end of the 19th century an English ironmaster complained to Andrew Carnegie, "It is not your wonderful machinery, nor your unequalled supply of raw materials that we have cause to envy; it is something worth both of them combined, the class of young scientific experts who manage every department of your works. We have no such class in England." We then had fewer universities in proportion to our population than any other civilised country except Turkey;† once again it was proposed that an enormous technological institution should be founded to train engineers. John Stuart Mill suggested that the Church of England should be converted into a great Mechanics' Institute, and Lord Haldane urgently counselled his countrymen to follow the example of their competitors — particularly the Americans and the Germans — before it was too late. He had been greatly impressed by the achievements of the Hochschulen. "He would be a pedant," he wrote, "who thought that education alone could determine the commercial position of a nation. Yet more than ever, as science tends increasingly to reduce nature to subjection, education becomes important . . . Courage, energy, enterprise, are in these modern days of little more avail against the weapons which science can put in the hands of our rivals in commerce than was the splendid fighting of the Dervishes against the shrapnel and maxims at Omdurman . . . Throughout the industrial world of Germany one finds science applied to practical undertakings by men who have learned it in the universities and Hochschulen . . . We are rapidly being left behind . . . The double aim of the German university system is pure culture on the one hand, and on the other the application of the highest knowledge to commercial enterprise."

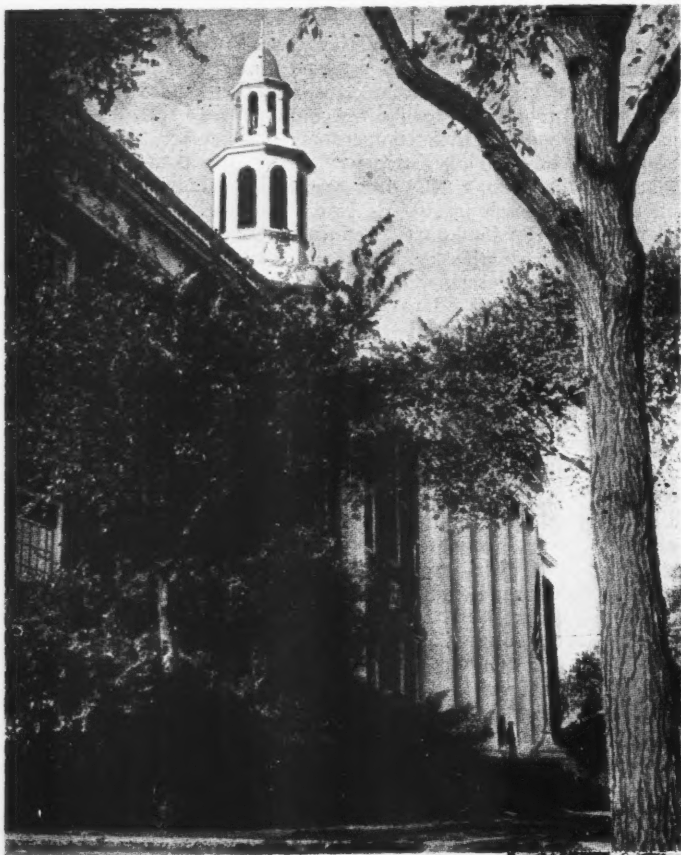
The outbreak of the First World War showed all the allied nations how dependent we had become upon Germany for many of the most important products of scientific manufacture; a note of alarm was sounded in this country, but nothing could be done at the time. Immediately after the War, the university population of Great Britain went up from about 20,000 to 36,000; it remained approximately constant for the next 20 years. After the last War the shortage of scientists and technologists led the Barlow Committee to suggest that the number of graduates in these subjects should be doubled, and that in order to preserve the balance of the universities, all other faculties should increase correspondingly. Our university population is now about twice as big as it was before the war, but it is only too clear that we are still desperately short of scientists and technologists.

No technological institution of university rank, comparable in size to the great European Hochschulen, has been developed in this country, but engineering schools have grown up in all our universities. This practice was deliberately rejected on the Continent, for the Continental universities themselves disliked the idea, and the authorities felt that the academic traditions of the universities might inhibit progress and prevent the free and proper development of these modern and "practical" subjects.* In Oxford University, for example, there are 14

* The first Chair in Organic Chemistry was founded in Manchester in 1874.

† This astonishing fact was pointed out by Ramsay Muir in 1901.

* The possibility of combining M.I.T. and Harvard was still being discussed 50 years ago (they are only a mile or two apart). The constitution which was then proposed for the amalgamated institution seems to have been in many ways similar to that which governs our own association with Manchester University. It is interesting to speculate on the possible development of this great Institution had this change been made. Harvard is like an English University in that it has a flourishing engineering school, but we have nothing in England like the Harvard Business School, nor have we anything to compare with M.I.T.



Harvard Graduate School of Business Administration — The Baker Library.

Harvard Graduate School of Business Administration — The Faculty Club.

Environs of Manchester College of Science and Technology.

Professors of History, 12 Professors of Science, 11 Professors of Classics and one Professor of Engineering. In Cambridge there are six Professors of Classics, eight Professors of History, nine Professors of Physics and Chemistry and five Professors of Engineering. The first Professors of Electrical Engineering and Chemical Engineering were not appointed until after the last War. Manchester University, always enterprising, appointed its first Professor of Engineering in 1868. There are now three Professors of Engineering among the 18 Professors in the Faculty of Science. There are 23 Professors in the Faculty of Arts. Two years ago there were four Professors in the Faculty of Technology in this College : we now have 10. In 1955 there were 65 ordinary Professors in the Technische Hochschule in Aachen and eighty in Delft.

Enlargement of Existing Colleges

The Government has been urged (particularly by Lord Cherwell) to found a completely new Institute of Technology, and a site near Ascot was once designated for its development. After prolonged debate and discussion it was decided to enlarge three existing Colleges of Technology—Imperial College, London, this College in Manchester, and the Royal Technical College, Glasgow. Each of these institutions is quite small by Continental standards, and each is very closely associated with a university. The Government has also announced its intention of spending about £70,000,000 within the next five years on the expansion of technical education throughout Great Britain —Lord Hives is presiding over a National Council for technological awards; eight technical colleges, one of which is the Royal Technical College, Salford, have

been designated colleges of advanced technology, and they are to prepare their students for a new award—the Diploma in Technology, which will be of the standard of a university degree.

Seventy million pounds may seem to be an enormous sum of money, but let us try and get it into perspective. It is about twice as much as the annual budget of the U.G.C. from which the whole of our university system has to be financed. We spend nearly four times as much in advertising every year and at least 12 times as much on liquor. The Government is in fact proposing to spend the equivalent of 30/- a head of the population in five years on technological education. This sum of money would buy 30 cigarettes a year for every man, woman and child in the country. Is it likely to be adequate to make up for the neglect of half a century and put us in a position to compete with confidence with other industrial countries?

Our position is now very much worse than that of either America or Russia or even Western Germany, which has developed both education and industry in a quite extraordinary way since the end of the War. In the winter of 1946 students in the Hochschule in Aachen were sitting on planks in unheated rooms in broken, ill-equipped buildings, but nevertheless they were earnestly and enthusiastically pursuing their studies. Before the war Aachen was one of the smallest of the Hochschulen and had between 800 and 1,000 students. After the war Charlottenburg was inaccessible, so it was decided to enlarge the school in Aachen, which has now been rebuilt and expanded to accommodate more than 6,000 students. Let us repeat it, in the last ten years the Germans have built an almost entirely new Technological University comparable in size to the University of Cambridge, which is devoted entirely to the education of scientists and technologists. There are no colleges, of course, and there is only one small hall of residence for about 300 students; the buildings are not all finished yet or completely equipped, but lecture rooms and laboratories have been built and 6,000 students are using them. The Government of Westphalia made the necessary funds available, for they knew that their whole economy depended on their engineers.

TABLE SHOWING NUMBER OF FIRST DEGREES (BACHELORS DEGREES IN SOME COUNTRIES, DIPLOMAS IN OTHERS) AWARDED IN "PURE SCIENCE" AND TECHNOLOGY IN 1954

Country	*Pure Science*		*Technology*	
	Total first degrees	No. per million population	Total first degrees	No. per million population
U.S.S.R ...	12,000	56	60,000	280
U.S.A. ...	23,500	144	22,500	137
West Germany	3,450	67	4,450	86
France ...	1,760	41	2,988	70
U.K. ..	5,200	105	2,800	57
Italy ..	2,436	51	2,200	45
Switzerland	215	44	399	82

The standards of these degrees are all about the same, although it is difficult to compare them in detail. Many European technologists—perhaps the majority, are M.Sc., rather than B.Sc., by our standards. The figures do not include such qualifications as Higher National Certificates. Large numbers of candidates take such diplomas every year in England, in Germany, in Holland and in Russia, but not so many do so in America. If we make allowances for them our position relative to some other countries is slightly improved. There were about 240 fewer graduates in technology in England in 1954 than there had been in 1950.

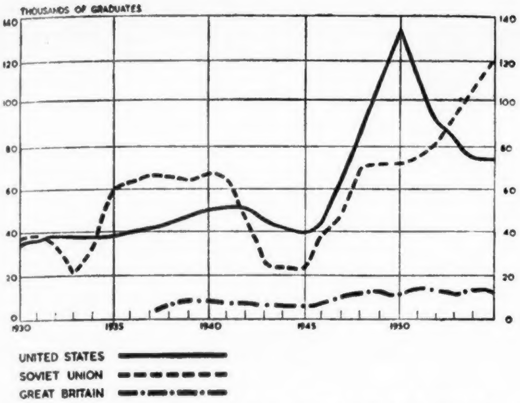
TABLE SHOWING POST GRADUATE DEGREES IN SCIENCE AND TECHNOLOGY IN 1954 (PH.D. IN ENGLAND AND AMERICA, "CANDIDAT" IN RUSSIA).

U.S.S.R.	4,500
U.S.A.	3,500
U.K.	900

There are now eight Hochschulen in Western Germany, with a student population of about 30,000. The country was almost bankrupt in 1946 and its industry was in ruins. To-day Western Germany holds dollar reserves greater than those of the whole sterling block. German exports increased by 18 per cent. between 1954 and 1956, ours increased by only 7 per cent. Why?

Sir John Mountford, speaking to the Court of Liverpool University in 1955, said "The one thing of which we have been starved has been the provision of buildings in which to carry out our work. Our experience has been one of continuous disappointment and frustration; within the foreseeable future, unless drastic action is taken now, the situation for the universities will become unmanageable and from a national point of view quite disastrous."

American productivity and the American standard of living are the envy of the world. The Americans are spending what to us seem to be almost incredible sums of money on university education; in some States more than half the young people go to college. In the whole of the United States there are about 18 undergraduates per 1,000 of the population—we have only two. In Russia there are eight; there are four in Scotland and six in Australia. Despite all that the Americans have been able to do, they estimate that their industry desperately needed 40,000 fully trained engineers last year, but only 22,500 graduated. The shortage is an acute handicap to the development of private industry, but it has become a matter of vital importance to the very survival of the country because of its impact on military research.



Graduates per year in all scientific fields, including Medicine, in the United States, Soviet Union and Great Britain.

The Americans are now becoming extremely anxious about their failure to match the recent progress of the Russians. In April 1956 President Eisenhower established a National Committee for the Development of Scientists and Engineers; he instructed it to " foster the development of more highly qualified technological manpower ". It has been found that 60 per cent. of the best qualified students in secondary schools do not go to advanced institutions and half of those who go do not get a degree; only a small percentage obtain a Doctorate. Moreover, although 12 per cent. of all College students studied Engineering in 1950, less than nine per cent, did so last year. Twenty years ago 10 per cent. of American undergraduates read Science; last year less than six per cent. did so. If the present trend continues for a few more years, the Americans will be doing little better than we are now. All this is true, although for at least 20 years the Americans have sent nearly nine times as many of their young people to the universities as we do in this country.

This unexpected and catastrophic decline in the number of American engineers should be a warning to us in this country. It seems to have occurred, despite the magnificence of the American universities, because of the shortcomings of American schools. Science masters in American schools are grossly underpaid : they can easily double or treble their salaries by working in industry, and most well qualified science masters left the teaching profession years ago. Despite the glamour and publicity with which science and technology are surrounded in America, it has become clear that schoolboys who are never taught science and mathematics properly at school are unlikely to become scientists or engineers, and only four-and-a-half per cent. of American High School students studied physics last year. Moreover, the Americans have discovered that a salary scale that treats all their schoolmasters alike, however well or however badly qualified they may be, is bound sooner or later to drive the best schoolmasters from the profession, leaving it manned entirely by its least useful members. This result would not have surprised Thomas Gresham, who announced 300 years ago that if two kinds of money are simultaneously in circulation, one of which is good and one of which is debased, " the bad money drives out the good ".

The table* below shows the number of reasonably well qualified men who are teaching arts on the one hand and science on the other in 66 secondary schools in this neighbourhood, tabulated as a function of the age of the teachers.

TABLE SHOWING NUMBERS OF ARTS GRADUATES AND SCIENCE GRADUATES TEACHING IN 66 GRAMMAR SCHOOLS IN THE NORTH-WEST OF ENGLAND

Year of Birth of Graduate	*Arts Graduates*		*Science Graduates*		*Science as Percentage of Arts*	
	1st and 2nd Class Hons.	Total	1st and 2nd Class Hons.	Total	1st and 2nd Class Hons.	Total
Before 1900 ...	50	117	36	82	72	70
1900 - 1910 ...	124	189	82	145	66	77
1910 - 1920 ...	195	256	85	151	43	60
After 1920 ..	244	333	62	160	25	48

Three-quarters of the ablest young schoolmasters are non-scientists. They must inevitably persuade hundreds of their pupils to follow in their footsteps, although many of them might do well in science if they had a chance. The situation is likely to get rapidly worse.

Each Girls' Grammar School in England is now able (on average) to recruit one good honours graduate physics mistress once every 100 years ; we have never had many women technologists in this country.

A comparison between the salaries that can be earned by English science graduates in industry and those that their contemporaries command as schoolmasters shows at least one reason why science masters have become so scarce in England. By the time he is 40 a science graduate in industry or the scientific branch of the Civil Service can expect to earn at least 50 per cent. more and probably twice as much as he would have earned as a schoolmaster. Good science masters are a dying race in England; the species is almost extinct in America, though it flourishes in Germany where grammar-school masters command adequate salaries; moreover, their profession is still admired and respected by the public.

This is not the place to discuss the shortcomings of our secondary schools or the inadequacy of their buildings; more than half of them have no proper laboratories for their sixth forms, most of them are overfull and have no hope of additional buildings for several years to come.

* Egner and Young, *The Staffing of Grammar Schools*—Liverpool, 1954.

Manchester College of Science and Technology. Plan of development areas.

A Deeply Rooted Problem

The whole problem is very deeply rooted in our educational system. Many a child who has been taught arithmetic badly at school is frightened of science for the rest of his life. There is a shortage of mathematics and science teachers in our primary schools, yet the average women teachers' training college devotes nearly ten times as long to the study of arts and crafts as it does to mathematics and nearly three-quarters of the colleges have no "education" lecturer who is qualified in this vitally important subject. A survey* has recently shown that about 50 times as much effort in all training colleges goes to arts and crafts as is devoted to physics or chemistry; and this at a time when our whole national economy depends entirely upon applied science and technology.

We may well ask ourselves if the Government's plans for increasing our national output of technologists are realistic unless something is done to help the schools. Before the war the teaching of science in the sixth forms of English schools was probably the best in the world. Shall we have to watch this great national asset being cast away? Nothing but the superb specialised education in science and mathematics that has been traditional in our schools has made it possible for our graduates—who have three years at a university—to compete with their Continental contemporaries, who usually have five or even six years university training. We should find appalling difficulty in introducing the Continental university system here, but we may have to do so if our schools can no longer maintain their standards in their sixth forms.

The expansion of technological education in Russia has been extraordinarily rapid. The Russians copied the example of the Germans a hundred years before them, and based their whole industrial expansion upon an enormously expanded educational programme, but they have bettered their masters. For example, the Baumann Institute in Moscow was founded as a trade school in 1830, when it was very much like this College had been in 1824. By 1924 it had grown so much that it was necessary to make it into a "Monotechnic", which specialised in the education of mechanical engineers. In 1934, 450 students graduated there and the Institute has grown rapidly ever since. It now houses a staff of 750 and there are 10,500 students who are taking courses of study which involve about 5,000 hours of instruction spread over five-and-a-half years. (Most English undergraduates have about 2,500/3,000 hours of instruction in three years.)

There are 30 other engineering schools in Moscow which accommodate altogether nearly 150,000

* *The Supply of Mathematics and Science Teachers*—Methuen, 1956.

students, about one-third of whom are women. The Russians are certainly producing far more technologists than the whole of the Western World put together.

In their anxiety to increase the number of engineers the Russians have not neglected the pure sciences. Moscow University now has 24,000 students (of whom 16,000 are taking internal degrees and 8,000 external degrees); 65 per cent. of these students are taking degrees in science and 35 per cent. in the humanities. Six thousand students live in hostels.

The Russian students spend about eight months in industry and they write a thesis during the last six months of their course. The standard they achieve seems to be very good; they are not as well prepared as ours when first they reach the university, but before they complete their course they have a good general education and ample time for specialisation.

The reconstruction of the University of Moscow must have cost more than the British Treasury has spent on the expansion of all our universities since the War. It stands in the very heart of the city on a 300-acre site that was ruthlessly cleared only five years ago. But this is not the end of the building programme in Moscow, nor is Moscow the only Russian university that is growing rapidly; Leningrad has an enormous university, and the University of Tiflis in Georgia has been expanded to accommodate 16,000 students of science and engineering. All students have a maintenance grant that is independent of the income of the parents. No student of science and engineering has to do military service. One-third of all graduate scientists become teachers—the profession is sufficiently well paid to make it attractive to them. The whole of Russia's educational system is based on science and technology as firmly as the English system was based on the classics 70 years ago. It was once almost inevitable that a clever boy in a good English school would study classics; clever boys in Russia to-day almost as inevitably do science. Most intelligent children (both boys and girls) can successfully learn any subject which is properly taught to them in school.

Need of Development

Russian industry has developed at a speed that is without precedent in history and it is undoubtedly the entry of so many well qualified men and women into the industry that made it possible for it to grow so fast. They had to make industrial workers out of an illiterate peasantry in a hurry, and they did so by giving them a formal education. The result is that they have, for example, a dozen times as many metallurgists as we have for every ton of steel they make. Our steel is as good as theirs and as well made, but their output of steel increased by 60 per cent. during the last five years. We expect to double our output in 20 years; after the end of the War the Russians doubled theirs in seven years. They already make more than twice as much steel as we do and there is no doubt that an industry manned by graduates will be more versatile and more receptive of new ideas than one like our own, in which most of the operatives have come up "the hard way" and learnt their trade on the shop floor, though these are the men on whom British industry relies to-day as it has done for a hundred years.

The Russians will in future be able to supply qualified technologists to all those countries in Africa, South America and Asia that are trying to develop their own industries. These men are the missionaries of our modern age; they will have enormous influence on those many countries now watching the cold war between Communism and the Western countries with great interest but with some measure of detachment. How are we to compete?

Extent of Russian Influence

There is no doubt that if we allow ourselves to be out-distanced technologically by Russia and if the rest of the world discovers that we can now give less than Russia can, then the rest of the world will tend more and more to fall under Russian influence. Our own culture may be forgotten after it has been swamped by Soviet technology. The fate of the whole world may be determined in the end by places like the Baumann Institute and not by hydrogen bombs. The effect of inadequately trained staff on an industry is insidious and most difficult to assess. No one can possibly say what a firm might have achieved had it recruited more technologists in the past. British industry is finding more and more difficulty in competing in the world. We may yet lose our markets one by one. We may end with a whimper and not with a bang. Though if our young people have a chance to show what they can do, this country may prosper as never before.

Which are the first things that should come first? When Mr. Malenkov visited this country he saw some modern English housing estates; he expressed his amazement—there is nothing like them in Russia; the Russian housing programme is miserably inadequate as compared with our own, but Malenkov remarked that inadequate though Russian housing may be, he proposed to cut the housing programme still further in order to spend more on education.

We may well ask ourselves how British industry has survived at all in view of the fact that the universities have failed to provide it with enough recruits. It is not surprising that some of our industries are backward, but it must appear to be almost a miracle that they are left to us and that some of them are thriving. We sell aeroplanes to America and we still hold all the world's speed records on land, sea and air. How have we done it ?

Before we congratulate ourselves too warmly on our mysterious gift for survival in spite of all the probabilities, let us recall the fact that we had many years' start over any other country in our development as an industrial power. Throughout the whole of the last century we were easily pre-eminent, but our principal competitors are passing us one by one. The disaster that threatened our industry if we failed to educate more technologists was foretold in a great meeting in this College in 1912; the inadequacy of our educational system has become more and more obvious ever since.

If the industrial revolution was made in this country by self-taught men, and by men who had been kept out of the universities by the Test Acts, it is equally true to say that much of British industry is run today by men who have never been near a university. They may have been kept out by poverty, by apathy, by tradition, by their strongly developed and instinctive preference for a practical training, or by their failure to satisfy the requirements of the Joint Matriculation Board. The many forms of training which they may have received are described in detail in Dr. Venables' comprehensive treatise on technical education. The system as a whole has long been the despair of academicians, one wonders if we have a system at all; is it not rather chaos, roughly organised?

In this part of England, there is a long-established tradition that a man who wishes to succeed in some industries can best qualify himself by leaving school at about 16 and spending some years "going through the works" while he learns his theory at night school.

Fifty years ago a distinguished visitor to this College told us that "Excepting only the private boarding schools, which we know as Public schools, there is no department of English Education in which such conspicuous success has been achieved as in the Technical Evening Classes."

Many of the leaders of local industry were educated in evening classes in this great College and other similar institutions throughout the country, "whose neglect by the authorities," said Lord Eustace Percy, "is surely one of the worst examples of waste in all educational history". However strongly we may feel that this practice has been made obsolete by the march of time and by the progress of science, we have to accept the fact that it will be with us for many years to come.

Any observer of the industrial scene of Manchester must be struck by the enormous variation between the scientific and technological standards that have been achieved by different local industries. Chemistry and electrical engineering, for example, have always been based on a rapidly developing scientific background, whereas textiles, paper making, printing and building, which are just as important, have developed from traditions hundreds of years old, and the skill and traditions of their craftsmen are still all-important.

Meeting the Needs of Industry

An educational system that provided recruits for one industry might be quite inappropriate for another. All industries need more skilled men, but whereas some of them could take all the Ph.D's. we could provide, others can make use of very few university graduates. I believe we should educate the most highly qualified recruits that each important industry needs.

The Barlow Committee reported in 1946 that four-fifths of the young people in this country who have sufficient intellectual ability to take a degree never come to the universities. We do not wish to "invest a ten-thousand-dollar education in every ten-cent child" any more than the Americans do, but only one-third of our children continue their full-time education beyond the age of 15; only 10 per cent. stay on at school after their 17th birthday. Four per cent. of our 20-year-olds are at the University, and 14 per cent. of the rest take part-time courses of one kind or another. What a waste of human talent is concealed in these figures!

It is of course true that nothing is ever quite so practical as a good theory, but many of our most successful engineers have been men whose whole experience has taught them to question the value of the academic approach. They always speak of bookwork as "mere" bookwork, and they regard the words "academic", "theoretical" and "impractical" as synonymous. One can appreciate and sympathise with this point of view, for there is much evidence to justify it. The industrial north still remembers the traditions of the last century, and often prides itself on its ability to develop and even to flourish without any help from the theories of the universities. Industry has always had at least as much to contribute to the universities as the universities have to industry. The history of all educational systems suggests that there is an all too common tendency on the part of academicians to divorce their teachings and their studies from the harsher realities of life. Despite the extraordinary successes of Greek science, it failed to develop as it might have done because of the complete lack of contact between the theory of the schools and the practice of the craftsmen who were ignored, misunderstood and despised by the scholars. Because neither scholars nor craftsmen could advance alone, both science and technology stagnated for nearly 1,000 years.

Any scholar who claims that his work is based upon an understanding of what he himself has decided are eternal verities, must find it humiliating in the extreme that a conclusion which may have been arrived at by processes of impeccable logic based upon quite plausible postulates, may be shown up as a farrago of nonsense by a direct experimental test of its consequences. If he refuses to concern himself with problems which admit of this acid test, the scholar may happily devote himself to mental exercises of extreme beauty, great sophistication, and of no practical use whatsoever. It is precisely this possibility which has coloured our educational system for 200 years or more; unless we are sufficiently enlightened to make good in a few years the neglect of a century, it may even yet bring us down in economic ruin. For this deplorable divorce between theory and practice the universities must accept most of the blame. It was a don who propounded the doctrine that there are two types of mathematics — "fundamental work" which is of no use to anyone, and "trivial mathematics" which may have great economic importance. Neither he nor his colleagues ever had the slightest doubt that it would be almost reprehensible for a man to devote himself to mathematics which might have major economic significance.

It is undoubtedly true to say, as Sir J. J. Thomson once remarked, that "If applied science makes improvements, pure science makes revolutions", but

pure science by itself is not enough, and an under-emphasis of the difficulty and importance of its application can be and has been dangerous. The same academic tradition which made our universities unwilling to accept science has made our scientists fail to appreciate the importance of applied science and technology—and underestimate the significance of what industry calls "development work". The glamour of research in pure science has obscured the fact that until the technologist has made his contribution, the discoveries of the pure scientists may have no economic significance whatever. The administrators who realised this more than 100 years ago and established great technological institutions in Europe and America built better than they knew.

Unfortunately, in England very few scientists have been as enlightened as Lord Kelvin, who, throughout the whole of his long life taught that pure science and technology flourish best in close collaboration. He saw on the one hand that the study of technology throws up many problems which should exercise and instruct scientists and, on the other hand, that the problems of the technologist can often be solved only by the help of pure science. Kelvin knew, for example, that Watt would never have invented the steam engine had it not been for the help that he received from Professor Black. The reciprocating engine which powered the industrial revolution was developed almost entirely by self-educated engineers. For many years the science of thermodynamics owed more to the steam engine than the steam engine owed to thermodynamics. No fundamental development in the principles of steam engines was introduced until a Cambridge mathematician named Charles Parsons invented the steam turbine. The early work of Parsons had to be supplemented by an immense amount of expensive time-consuming development work before his engine had any practical application.* It is in the very best English tradition that the gas turbine and the jet aero engines were invented by half a dozen young men (directed by Sir Frank Whittle). All the members of this team had first-class degrees in Engineering. The subsequent development of the engine has been in the hands of the great engineering firms, but (and this is a point which must be emphasised) the gas turbine was invented by a small team and has since been developed by large teams of engineers all over the world. The work of all these men has been equally necessary to its success.

The First Nuclear Fission

The pioneering work which led to the first nuclear fission was done in England, France, Germany and America — the very first artificially induced nuclear reaction was achieved by Rutherford in Manchester about 35 years ago. I doubt if there were more than a few hundred nuclear physicists in the world in 1939. Before the end of the War an entirely new industry had been developed ; most of the technical problems which had to be solved were entirely novel, and the industrial effort which had been required by the Atomic Energy Authority was comparable to that which would be needed to rebuild the entire American railway system. Why, therefore, should so many academicians believe the fundamental work to be all important and regard the development as . . . " mere development " ?

Where the Nation has Failed

While our scientific workers have been concerned with work which they felt would have great ultimate significance, we have failed as a nation to provide facilities whereby the results they have won could be made to produce their proper impact on society. Although we can accept the truth of Thomson's aphorism, we must always remember that the cost of the work which has to be done to develop a scientific discovery into something which can be manufactured on a large scale is always many times greater — often hundreds of times greater — than the cost of the initial discovery upon which the work ultimately depends. Moreover, the fundamental discovery can be made in any part of the world, but the development work must be done where the ultimate product is to be made and used. The pure science of this country has been of service both to this country and to the world as a whole, and has brought glory to the universities where it has been done. Nevertheless, the fact remains that we have had to buy the goods which resulted from our own scientific work from America, and we have had to pay for the right to use patented processes which were developed by the Americans from our scientific work.

We have always given due recognition to our great men, but we have failed to realise that much research depends at least as much upon man hours and money as upon individual genius. Very few men, even the most eminent, are ever more than a few years ahead of their time. A Newton could be 100 years in front of his contemporaries, but we cannot rely on a regular series of Newtons. In this country we have never understood the American technique of solving problems by " trampling them to death ".

It is most interesting to recall nowadays that although America has always endowed applied research, neither Government support nor private endowment was available in the United States for the promotion of pure research until late in the 19th century. Whereas in Europe almost all Governments supported science directly, Congress turned a deaf ear to all proposals for creating scientific institutions which were not content with limited utilitarian objectives. Washington's plan for a national university was strenuously opposed by the older universities. The first considerable sum for the support of pure science in America came from an Englishman, James Smithson, with whose bequest Congress created the Smithsonian Institution.

At the end of the War, Dr. Vannevar Bush was commissioned by President Roosevelt to make proposals for the development of American science and industry. Bush remarked that for very many years

* Many fundamental measurements on the properties of the nozzles and blades in Parsons' turbines were made in this College by Professor G. G. Stoney, F.R.S., who subsequently became Research Director of the Parsons Company.

American industry had relied upon the scientific work which was done in Europe for the discoveries upon which the prosperity of the country ultimately depended. All the fundamental scientific work which is done in the world is freely published and it is available to everyone; the Americans had not suffered any material loss because they were not doing enough basic work for themselves:

"Our national pre-eminence in the fields of applied research and technology should not blind us to the truth that with respect to pure research — the discovery of fundamental new knowledge and basic scientific principles — America has occupied a secondary place. From Europe came the formulation of most of the laws governing the transformation of energy, the physical and chemical structure of matter, the behaviour of electricity, light and magnetism. In recent years the United States has made progress in the field of pure science, but our efforts in the field of applied science have increased much faster, so that the proportion of pure to applied science continues to decrease."

Bush concluded that it was imperative that the amount of pure research which is done in America should be materially increased, in order that the standard of living of the American people should continue to rise. He felt that a nation which borrows its basic knowledge from others will be hopelessly handicapped in a race for innovation, and, moreover, that men who have been educated as pure scientists often develop into most valuable technologists. This is indeed a pragmatic assessment of science; but should we not accept it? Should we not conclude, moreover, from Bush's analysis that we need more applied science just as much as America needed more pure science in 1944?

For very many years trade and industry have not received in this country the regard that is their due. The business man and the engineer have always been more respected on the Continent and in America than they have been in England. Here it has usually been assumed that the professions were in some way more valuable to the community and that they offered a better career to a young man of high ideals. The profit motive has been suspect and industry has been accused of blind materialism. Fortunately, this tradition has almost vanished and the public understands that many people can contribute more to the public well-being by working in industry than they can in any other way.* Almost everyone realises nowadays that a man can expect a perfectly satisfactory career in industry (even if he is highly paid). It is essential that our industry should attract its fair share of the best brains of the next generation; its recruits must be adequately educated if they are to be fitted for their life's work. They will have to learn Science or Technology — or Russian.

One can understand the idea of "Art for Art's Sake". One can support "Science for the Sake of Truth and Understanding", but we must have TECHNOLOGY for the sake of survival.

* "The hope of commercial gain has done nearly as much for the cause of truth as even the love of truth." — BOVEE.

AUTHOR'S NOTE

The greater part of this material has been incorporated in a book called "The Future Development of the Manchester College of Science and Technology", now published by the College.

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"THE CHALLENGE OF THE AGE"

(concluded from page 74)

researcher to the retailer, for the progress of the commodities that play so large a part in determining our standard of living. A chain is as strong as its weakest link. and in the future the sums spent on research and the skill devoted to the development of new products will not earn their full returns unless the markets for these products can be quickly opened up and efficiently supplied. It would be misleading if I gave the impression that solutions for all these problems are easy to find or immediately successful in their application, but our experience has been that in the long run clear thinking, careful planning and a constant search for newer and better methods are well rewarded.

REPORT AND DISCUSSION

Chairman: Mr. H. G. GREGORY, M.I.Prod.E.,

Chairman of the Institution's Council.

OPENING the meeting, which was held in the Great Hall of the College of Science and Technology, Manchester, on 14th November last, the **Chairman** said that he wished to express to the College authorities the Institution's sincere appreciation of the facilities made available for this occasion. It was indeed a most appropriate setting for the present meeting, bearing in mind the speaker and the subject.

The Chairman recalled that the Sir Alfred Herbert Paper had become established by the Institution in 1952, in accordance with the wish of Council to honour some of its distinguished members who had given the Institution valuable service, by associating their names with authoritative Papers given by eminent personalities.

In allowing his name to be given to this Paper, Sir Alfred, who was a Past President of the Institution, had said that he would very much like the lectures to have wider applications than those confined to the narrow aspects of the metal working industries or the machine tool industry. The subject of the Paper to be presented by Dr. Bowden was one in which Sir Alfred was intensely interested.

The Institution was pleased to be able to present this Paper only a few weeks following Sir Alfred's 90th birthday, and the Chairman felt sure that those present would wish to join him in expressing warm congratulations and good wishes on this occasion.

With regard to Dr. Bowden, the Chairman said, he certainly needed no introduction. He was a man of eminence and authority in the educational and technological world, and the Institution was indeed privileged that he had accepted the invitation to present the 1956 Sir Alfred Herbert Paper.

(*Dr. Bowden then presented the Paper which appears on pages* 75/88), *after which the Chairman declared the meeting open for discussion.*

Mr. R. Ratcliffe, M.B.E. (*Chairman, Institution's Education Committee*): I am sure everyone here tonight must be delighted, although perhaps a little breathless, after listening to Dr. Bowden's erudite address with its indignant demand for an overhaul of our system of technological education and of the facilities available. How true is his final phrase: "We must have technology for survival".

Many of us have been disturbed by the slow pace of expansion of technological education in general, by the reluctance of the universities to broaden their base in technological subjects, by the failure of our grammar schools to steer an increasing percentage of the available brains into the fields of science and technology, and by the frightening situation of the lack of science teachers in the schools. There is still far too much intellectual snobbery about technology and its alleged lack of culture. This Paper tonight gives a glimpse of a cultural pattern in its review of early development. Why should we not encourage such inquiry and study, which has a cultural value in its own right?

Dr. Bowden's "call to arms" is a challenge to all who have the interests of the country at heart and who are concerned in any way with technology. Survival is the key word. We must not delay any more in at least matching the pace abroad.

Do not let us rush off and copy Europe and America; after all, we have an instinctive genius for developing systems that suit our own way of life, however untidy they may appear to foreign eyes. Do not let us attempt to turn our universities into super technical colleges, nor encourage the technical colleges to ape the universities. But surely the universities must realise they have a part to play by applying their own particular gifts, traditions and standards to many suitable aspects of technological development. I think it is tragic that very little effort has been made by the universities, even on a cultural basis, to study the history of technology and its influence on our development as a nation. In a more practical field their neglect of the technology of production engineering, the translation of ideas into reality, has been unfortunate.

As an Institution, we are vitally concerned with this technology of the conversion of ideas into reality and it is fitting that our discussion tonight should range round this concept. May I mention some points which I think need to be discussed:

1. What part should the universities play in developing a fundamental treatment of production engineering technology? Should it be post-graduate or can it replace other subjects in first degree courses?
2. Are sandwich courses the best approach for the technical colleges to make in organising the Diploma in technology courses? Is the present intention the best one, to concentrate in the first place on a small number of colleges on a regional basis? I believe it is.
3. What must be done to awaken the perception of industries who even today ignore the scientific method and, as Dr. Bowden states, still depend on manual skills? The sad fact is that further progress is being made largely by the enlightened. In my experience, technical colleges almost always meet the demands of industry — it is industry which must now present the demand in emphatic form and be prepared to support educational institutions by releasing students and lecturers.
4. What must be done to stop this fantastic situation of British ideas having to go abroad for development — the subsequent product being sold back to the United Kingdom?

   Dr. Bowden mentions the research and development effort on defence as if it were a restriction or diversion of effort from industry. But is it not true that, due to the defence research and development effort, the country gets a benefit which would not otherwise accrue? The aircraft and atomic energy industries are two excellent examples. What will happen if defence research and development are reduced?
5. Are we ignoring available talent in not using more women in the fields of science and technology?
6. Can we afford to delay any longer in not giving organised education and instruction to such a large proportion of our school-leavers?
7. How are we going to meet the need of the under-developed parts of the world? Must they be left to Russia?

Dr. Bowden *(left)* **chats with Mr. H. G. Gregory before the lecture.**

Dr. Bowden: I would like to comment on the points which have been made, but in no particular order. With regard to the training of the production engineers in this country, there are more undergraduate production engineers in Delft than there are in the whole of this country; there were 6,400 last year in America and 44 in this country. Before long we are hoping to create a Chair of Production Engineering in this College, and perhaps one in Machine Tool Design as well.

On the question of the contribution which is made by industry, I believe we have grossly underestimated what industry has in fact done. It is true to say that the Hochschulen provide courses of five or six years' duration: in this country our students have only three years in the universities. But the better English engineering students go on to become graduate apprentices; they very often have two years' training in industry at the expense of a firm, and get the equivalent of the extra course that foreign students have in the Hochschulen. Our great industrial firms must be spending at least as much—and I suspect very much more—on the training of graduate apprentices as the Government makes available for the training of all the post-graduate engineers in all the universities and all the technical colleges in this country put together. We must not underestimate what has been done by some industries. On the other hand, other industries have been astonishingly backward — the textile trade or the machine tool trade, for instance. The machine tool trade is made up of a large number of very small firms, no single one of which is big enough to sponsor a proper graduate apprenticeship scheme. I believe it to be absolutely essential for the future development of the machine tool trade that such a system should be inaugurated and that, by combining forces with several machine tool firms in the district, the college could work out a scheme which would effectively launch our graduates in the trade, in the same sort of way that a doctor is launched into the world after experience in a hospital. I very much hope that something can be done to introduce into part of this great industry the kind of scheme which has made the electrical industry, for example, what it is today. There is a common saying that all electrical engineers can be divided into two classes — those who work at Metropolitan-Vickers and those who used to work at Metropolitan-Vickers! Metropolitan-Vickers have, for years, performed a service not only for the benefit of themselves and their own engineers, but for the benefit of the electrical engineering industry of the country, and to the world as a whole we must not, in our anxiety, blame industry, and forget the contribution which some industries have made and will continue to make.

The other point which the speaker made was that we must get more help from industrialists in the way of part-time lecturers. Just as, for example, the Professor of Forensic Medicine is a police surgeon part-time, so one must get Professors Extraordinary in the college who are representatives of some local machine tool firms. These are the men who know some of the answers and who must be persuaded to come and explain to students some of the things they must know. One cannot expect a Professor of Surgery to be held in high regard if he never practises surgery, but a Professor of Engineering in this country may spend all his life in a university; this sort of thing never happens abroad.

I would reiterate the point that the number of Professors I quoted as being at Delft were full-time members of the university staff, and there are 65 part-time Professors Extraordinary as well as the 80 I mentioned.

Mr. J. France (*Head of Industrial Engineering Department, Loughborough College*): Dr. Bowden's survey has been worldwide. He has covered the whole of industry, the whole of science and technology, and his facts cannot be controverted. But we are mainly concerned with production engineering, and it is on that particular side that I think we ought to centre our thoughts. Those of us who have been in the fight for the recognition of production engineering education from the beginning will, I think, get a great deal of encouragement from what Dr. Bowden has said. After reading his Paper, I find that all the arguments that have been and are being used against the production engineers' views by the older-established engineering faculties are exactly the same arguments that were used against them when they started years ago. I feel that Dr. Bowden did not read the best part of his Paper, and it will be just as well if I read some of it for him.

For example: "The University of Berlin would not admit engineering to its curriculum because the other faculties considered that it was non-scientific"; "The University of Amsterdam refused to teach engineering or even to admit that it was a subject which could be taught at university level elsewhere". Doesn't it all sound familiar, gentlemen! These are the very arguments which, over the past 25 years, have been advanced by the now established engineering faculties against production engineering education, but it is encouraging to realise that they, too, had the same thing and that in spite of it they have got recognition today.

Dr. Bowden has, in his Paper, painted a very gloomy picture indeed of what will happen if we do not catch up with Europe and America. I suggest it will be more gloomy still if the full value of production engineering education is not recognised in time. If I may read another part of Dr. Bowden's Paper for him: ". . . the cost of the work which has to be done to develop a scientific discovery into something which can be manufactured on a large scale is always many times greater — often hundreds of times greater — than the cost of the initial discovery upon which the work ultimately depends". Could I add to that and say that the cost of developing its production must be thousands of times greater? That is a good reason for saying that much greater attention should be paid to production engineering technology.

Dr. Bowden goes on to say that the American Congress turned a deaf ear to all proposals for creating scientific institutions which were not content with limited utilitarian objectives. We production engineers have been accused of being too limited and utilitarian in our objectives, but the policy has paid a very good dividend in America.

Could I suggest that we would be considerably strengthened if the words "our industry" were interpreted as the production engineering side of industry, when Dr. Bowden says: "It is essential that our industry should attract its fair share of the best brains of the next generation: its recruits must be adequately educated if they are to be fitted for their life's work."

Finally, Dr. Bowden, I would like to misquote you: "They will have to learn the science and technology of production — or Russian".

Mr. H. Teasdale (*Chief Training and Education Officer, North Western Gas Board*): There are three aspects of Dr. Bowden's excellent Paper on which I should like to comment. They concern the divorce between theory and practice, the control of technological education, and the teaching of science in the schools.

Dr. Bowden has made a devastating attack on the ingrained English attitude towards technological education. If he has not scared us, we are indeed complacent. Although his Paper is concentrated propaganda, I am sure he is not in the least ashamed of it because he really believes — as I do myself — that he is dealing with a subject which is a matter of life and death for Britain.

Dr. Bowden, although anxious to get his message across, has not adopted a partisan attitude ; in fact, his treatment of the subject consists of a really catholic presentation of the facts. No doubt because of his extensive industrial experience, he does not underrate the widespread scepticism among practical engineers regarding the academic approach. In fact, he agrees that there is much evidence to justify it and believes the universities must accept most of the blame for the divorce between theory and practice.

I have long believed that the most effective antidote to the academic disease from which the universities suffer is pre-university industrial experience for *all* scientific and technological students. Those of us who have taught advanced part-time students in technical colleges know only too well how impossible it is to get away with pure theory and airy generalisations. Students with industrial experience make continual demands upon their lecturers to relate their theory to day-to-day practice as experienced by the students themselves.

My second point concerns the delicate subject of control. The form of control we have adopted has been largely responsible for the sluggish growth of technological education in this country. The universities control part of technological education, the local education authorities, the remainder. The university attitude towards technology has been dealt with fully by Dr. Bowden. May I briefly refer to the other part of the problem.

While I do not wish to offend those who perform valuable, voluntary civic duties, the situation calls for some plain speaking. Recently, the Minister of Education delivered a forthright address in the North West, at the General Meeting of the Union of Lancashire & Cheshire Institutes. He strongly emphasised that his department had been advised by the leading scientists in the country to take control of the proposed advanced colleges of technology out of the hands of local education authorities. He did not say why he had not accepted this advice. Presumably it was because of political considerations. Otherwise, it does not make sense to leave control of the development of institutions serving vital industrial needs in the hands of civic representatives, most of whom will not have had personal responsible experience in the field of industry, science or technology.

The advanced colleges of technology should not in any way be financed from the rates. Why should residents of Salford, for example, pay, except through taxation, for the education of students from Wales or the South of England? It is not that the students educated there are likely to serve local industry. The whole problem of advanced technological education is a *national* problem. It should be financed nationally and be guided and assisted primarily by leaders in the fields of industry, science and technology.

There are, of course, signs that industry is becoming aware of the lead it must take if we are to climb out of the abyss into which we have sunk. The F.B.I.'s Industrial Fund for the Advancement of Scientific Education in Independent and Direct Grant Schools is a most encouraging sign of industry's realisation of the danger of neglecting school science, to which Dr. Bowden has so forcibly drawn our attention. I have the feeling that the weakness of science in our grammar schools is the most menacing problem of all. We simply must get back to the pre-war position. To do this, *we cannot avoid* paying science and mathematics teachers salaries which are comparable with those they can earn in industry, and therefore superior to those which teachers of other subjects can earn. Science subjects must become pre-eminent school subjects. Since the Burnham Committee will resist differential salaries, it may be necessary for a pensionable state bonus to be paid to science teachers, in addition to their salaries. Whatever measures are necessary, one thing is axiomatic: we must plough back into our schools a good proportion of their scientific produce.

Dr. Bowden: I have three points. First of all, although the differentiation of salaries in schools is likely to be opposed, there is already a substantial difference between the salaries earned by graduates in different subjects The Government has sponsored a survey of the salaries earned in 1954 by men who graduated in 1951. It was found that men who graduated in technology had better salaries (on average) than men with first-class degrees in science or the arts.

The next point is that the difference between the salary scales of teachers in schools and the salary scale of the same sort of men outside the schools is very great and, until something is done about it, there is no doubt that the best people will go—as many have already gone—away from the schools, and that is very serious.

The third point is this, that I believe our entire educational system is still, in essence, based on the assumption that we are trying to train classics. The man with the practical approach, the man with an intuition how things work, never really gets an opportunity of displaying his talents at any level below the university. In an ordinary school, the whole of the training is based on the assumption that all information is to be found in and learned from books, and I believe that this has never really been properly appreciated as being one of the defects of our educational system. A child of $5\frac{1}{2}$ is put in school, at which age he is full of enthusiasm, drive and energy, and he does not believe what everybody tells him; he wants to try things for himself. One expects an engineer to be enterprising and imaginative and not to believe all that he is told, but to try things out for himself. There is something quite fundamentally wrong with our educational system

At the reception — on the left, Mr. H. Spencer Smith (Past President of the Manchester Section) with Mr. Robert Douglas, M.B.E., M.I.Prod.E. Mr. Douglas was the author of the 1954 George Bray Memorial Lecture.

and I do not quite know how it can be put right, but until we devise a method which will preserve this boyish enthusiasm in our youngsters—nowadays it is ground out of them—we shall not get the engineers we want.

Mr. W. S. Hollis (*Assistant Director, Aircraft Production Development, Ministry of Supply*): Dr. Bowden's Paper shows considerable knowledge of the background history of world industrial development. Most of us, whose knowledge of this subject is limited to that of the Industrial Revolution of Great Britain, are appalled by the lack of thought and provision exhibited in the 19th century and are concerned for the present outlook.

There is, I would suggest, a trinity of Researcher, Development Engineer and Production Engineer. The Researcher exercises the original or inventive thought; the Development Engineer builds without specific reference to time or money; and the Production Engineer brings the project into productivity by means of a series of manipulative operations, based on the certainty that his work has detracted nothing from design or functioning, but added cheapness, interchangeability, removed tedium, improved quality and used better suited material.

In a competitive world, markets will be held only by superior design and cheapness. There is relatively a small percentage which can command sales on technical superiority alone, whereas a great field of commerce is determined on price exclusively. If we are to exist, our markets must be preserved by greater output per man, and this is where production engineering requires, and indeed this Paper states, that skill handed down through the generation must be replaced by the demand for skill to manufacture equipment giving reproductive as well as productive output. Our youth should be taught that the technology of production engineering ranks equally with the technology of design and development.

Our American friends have a native ability to get into production while we are still at the talking stage, and although the problems of getting a move on are still likely to be regarded as a science, we do need informed opinion to guide wisely on those technical improvements which are imperative for the re-equipping of industry, and to decide without hesitation when the gap in our production ability is apparent.

I feel the most impressive of the summaries in this Paper is that section which deals with the supplying, in the future, of qualified technicians to the African, Asian and South American markets. These emissaries will use the text-books of compatriot authors and the extent of technical knowledge, except for the more advanced levels, will be bound to them. This is a field in which, on account of numbers, we cannot hope to compete.

In my own field of production development, I find that research relating to the machining process and that concerning new metals is mainly American, resulting from the many developments sponsored by American authorities and carried out at the various universities of that country. Bowden, Tabor and Trent, British investigators of the friction and cutting process, are quoted frequently and in historical order with Amonton and Coulomb. Merchant's application of orthogonal machining for his research at Cincinnati University was adopted from earlier work by Stanton and Hyde reported to the Institution of Mechanical Engineers thirty years ago.

In surveying the vast quantity of information which is reaching the United Kingdom in this manner, and in examining the D.S.I.R. Russian translations of technical publications and theses relating to work being investigated in the universities of that country, I must agree that the statements Dr. Bowden has made are well-founded and merit sober consideration.

Dr. Bowden: An engineer can do for a shilling what any fool can do for half-a-crown or a Government Department will do for five shillings. I hope I can say that without offence in present company!

Mr. H. E. Dance (*Staff Inspector, Ministry of Education*): An educational system grows out of the social and economic structure of a country; it cannot be changed without changing the attitude and behaviour of the country as a whole. I agree with what Dr. Bowden has said tonight, but I do not think he has said enough. This problem has to be tackled from all sides. Engineering education has developed the way it has done in the U.S.S.R. because engineering is the most socially respectable of jobs there; everybody wants to be an engineer and therefore everybody who can goes for engineering education; consequently, the application lists contain three or four times as many as they can accept. Women have a large share in engineering education in the U.S.S.R., because women are employed on equal terms with men in *all* jobs in the U.S.S.R. You may see women engine-drivers, women surgeons, women professors of engineering and women technologists; wherever men do a job, women do it also. It is not so in the U.K. and it will take time for the social change implied by the general employment of women in engineering to come about. But it will come about by patient persuasion on all fronts, and we should help that persuasion as far as we can. We may have to have men teachers of science in girls' schools, because if women science teachers are not there, who can teach it?

Dr. Bowden, in speaking of universities and "night schools", has omitted one of the most important developments in education in this country, namely, the part-time day courses which, in engineering, apply to about 90% of the students in technical colleges. In order to draw a fair picture, let us examine the figures. Taking all the University Degrees, the University and Technical College Diplomas and Higher National Certificates: before the War, the Higher National Certificate awards amounted to about 40% of the total. The whole lot has multiplied three times from 1948 to 1954, but the proportion of Higher National Certificates has risen from 40% to over 60%. I do not suggest that these streams of entrants into engineering are equal or that the part-time day course is sufficient, but it contributes two-thirds of the total in engineering. Many firms give their apprentices more than one day a week release and others adopt block attendance schemes. Firms with large recruitment and training schemes are selecting the best National Certificate students and placing them in sandwich courses, which give much more time than a part-time day course can give. Nevertheless, the number of people who are coming into part-time Higher National Certificate courses — the increase in the numbers *per annum* —is more than the numbers being taken off those courses to go into sandwich courses. There is no indication that the numbers who enter engineering through Higher National Certificate courses will fall.

Dr. Bowden: One of the reasons for the success of engineering in Russia is the fact that engineers are the highest paid members of Russian society, and Professors of Engineering are the highest paid of all engineers.

Mr. B. Dawkins (*Chief Assistant, Professional Training (Electrical), Metropolitan-Vickers Electrical Co. Ltd.*): I would like to refer to the shortage of science teachers and lecturers, which I think Mr. Norman Fisher referred to earlier in the week. We are finding very great difficulty keeping the standard of our graduates up to a high enough technical standard for original research and design work, and for that purpose we have instituted lectures in physics, mathematics and associated subjects, and we have at the moment 45 qualified engineering and science graduates teaching on these lecture courses. We know this is the pattern in other large companies, but I think you will agree that these are figures which do not appear in statistics.

I would agree with two earlier speakers about the growing need for sandwich courses. I think there is a very real need at the moment — as came out at a recent national

conference of people representing apprenticeship and training in industry — for assessing the real needs for graduates in industry. There is a great tendency towards not using the existing graduates to the full.

I believe that Dr. Bowden said Gibbon referred to his university career as the most idle and unprofitable period in his life; it has also been referred to as the only holiday a man gets between his mother and his wife!

In this country we have at the moment a three-year — in some cases a four-year — degree course, and not five or six years as they have on the Continent. I am wondering whether you can give your views, Dr. Bowden, on the need for a more fundamental approach in the teaching in universities? This may save time by getting over fundamentals, which are sometimes lacking. I would also like to know the percentage of girls studying on the Continent and in the U.S.A., as well as those figures you have given us concerning Russia. Lastly, I would like to hear your views on the need for a more liberal education for engineers and scientists.

Dr. Bowden: If I attempted to answer all these points, it would take almost as long as my Paper took to deliver. First of all, if I may be forgiven for saying so, I have answered most of them in my book.*

In the first place, our students are better prepared, even yet, when they leave our schools, than are the students in any other country which is known to me. I think that they are a year ahead of freshmen students in universities in America and Russia. This is achieved at the price of the literary education which is also so very necessary. But I do believe that we could do something to make up for it in our colleges. I would like to recommend — and I have already recommended many times — that instead of trying to give our people an ordinary literary education in the accepted sense, we might have a course suitable for them in the history of science and technology, which has had such a profound effect upon the history of the country and of the whole world.

The courses, in universities in this country, may reasonably be one year less than those on the continent. Of the five years in a Hochschule, at least one is spent in industry — or six months, anyway, and I believe much good would come from a proposal to make our students take a course in industry as part of their academic training. In most aeronautical departments in English universities, the demand for places is so great that the Professor can impose any condition he likes; some of them do not admit people unless they have had a year in a firm such as yours, Mr. Chairman, or other firms of equal reputation. This is all to the good. If I may generalise freely, I think that the English educational system — in universities — is very much better organised than the training in many Continental Hochschulen. I think that a man who has had a university course and a graduate apprenticeship in England, is at least as well, if not better, educated than his European contemporary. I had an opportunity of discussing this matter in Holland with the Director of Research of a very large industrial concern. He says that he has compared students from Delft, who have had six-year or seven-year courses and then a two-years' graduate apprenticeship, with Englishmen who have had a three-year course and the same two-years' post-graduate apprenticeship, and he says he cannot tell one from the other. He says that Continental students are often better for research work because they have more opportunity to study mathematics than Englishmen do. I do not think one can be sure, but we are not quite so badly off as the very large disparity in the university courses might suggest.

As for the other general questions, I am afraid I shall have to ask you to read my book!

Principal H. Cheetham (*Walsall Technical College*): I would first of all like to thank Dr. Bowden for his most stimulating Paper. It has been well worth the journey from the industrial Midlands to the industrial North-West. I would have liked to have heard more from Dr. Bowden about the present plans for the expansion of technical education, although I realise that it might be slightly outside the scope of his Paper. I myself am not sure that the present plans go nearly far enough, and, whilst I would not like it to be thought that I am decrying the merits of National and Higher National Certificate holders, I do not really see how the student or the young man who has left school possibly at 15, but certainly at 16, and who does part-time education to the age of 21, can possibly have the same academic standard overall as a young man who has remained in full-time education through the grammar school sixth form and three years at university.

With regard to this intellectual snobbery which has been mentioned, I always wonder whether that same snobbery is still existing in that although we are to have this expansion of the technical colleges into colleges of advanced technology, the students who undertake the new courses will still not be awarded a degree. It may be that a diploma in technology will be of equal standard, but will it be held in the country at large to be the equal of a degree?

* "The Future Development of the Manchester College of Science and Technology." Available from the College, price 5s.

Mr. H. E. Dance *(left)* of the Ministry of Education, discusses educational problems with Mr. R. Ratcliffe, M.B.E., Chairman of the Institution's Education Committee, at the reception preceding the Manchester Meeting.

Three prominent members of the Manchester Section are obviously enjoying the occasion: *(left to right)* Mr. T. A. Stoddart (Manchester Section Chairman); Mr. F. W. Cranmer (Past Chairman, North West Region); and Mr. R. H. S. Turner (a Past President of Manchester Section).

I would like to comment on sandwich courses, which are still somewhat experimental, and my remarks are directed more to industry than education. The young men who are undertaking sandwich courses will (in each year) do six months in college and six months in industry. I feel that the six months in industry should be regarded primarily as education, and the employers should see to it that they do everything in their power to assist educationally, and not use the six months in industry to try and catch up on the production work of any man (whether design or production) in relation to the six months that they have been allowed at the technical college. I am aware that many employers do spend very considerable sums of money in providing facilities for the training of their young men by sending them to technical colleges and universities. There are many other employers (even in the engineering industry) who do as little as possible in that direction, and that applies not only to advanced studies but to the normal craft apprenticeship. I have no axe to grind at all; I am not connected with industry, but I do feel that those firms who are providing these training facilities should get the most generous tax concessions from the Government, in order to ensure that their work in providing these training facilities does not go unrewarded.

Finally, one of the speakers has commented on the fact that we cannot hope to compete with the U.S.A. or the U.S.S.R., because we have not got the same numbers. I would say that, because we have not got the total population, because we are dependent absolutely on our capacity to export, we should do more, in proportion, than the other countries and see that we export our brains and skill, which, of course, would be the best way of making use of our limited resources.

Dr. F. Koenigsberger (*Manchester College of Science and Technology*): First of all, may I strike a slightly more cheerful note than Dr. Bowden? I am a product of a German Technische Hochschule and I remember that there, too, our colleagues from the Arts Faculties called engineering students the "plumbers".

With regard to the snobbishness of university-trained men, which has been mentioned, I feel that the direction of attack should go partly towards industry, where there is an equally critical snobbishness directed against the "men of theory" by the men who have come up the "hard way".

There is, however, a great need for pre-university practical training, not only because it is essential, as one speaker said, that a student should know what a lathe is before he can be taught the theories of metal-cutting, etc., but also because in my opinion an important function of such pre-university training is to teach the student humility. This will automatically eliminate any snobbishness when graduate engineers come into industry for the first time.

When I got my first job in an industrial drawing office after I had obtained my university degree I was told straightaway that, unless I could do my work as well as any draughtsman, or better, I was no good. I should add, however, that it is equally important for industry to give graduate engineers a chance of promotion in the technical field. I do not speak now about managerial positions, but I wonder how many chief designers, the men who really design machines, are for instance Ph.D's? You do find many of them in design and drawing offices on the Continent.

As regards attracting people to the study of engineering, I would like to quote an example from America, where, for a time, the foundries were complaining that they did not get a sufficient number of foundry engineers from the universities. The foundry organisations or works got together through one of their institutes or associations, and made a levy of one dollar per employee of each foundry or works. The money collected was used for scholarships for students proposing to take foundry engineering, and a sufficient number was reported to have been attracted in this manner.

Dr. E. G. Edwards (*Principal, Liverpool College of Technology*): I would like to comment on the question of this transition that we hope to see in the near future from our traditional evening or part-time courses to a more liberal and wider system, such as we foresee in sandwich courses. The point I want to make is that there are two major advantages which will arise from this. One of these is the elimination of waste, because one of the major difficulties of the evening or part-time system is the enormous amount of waste of promising people who, with a wider opportunity, could have attained full professional status. The second major advantage is the broadening all-round education of the engineer. I feel that the facilities which we have at the moment could be much more efficiently used, and we could turn out more engineers per year, if the rate of transference from part-time to full-time and sandwich courses could be increased.

So far, this development has been very largely spontaneous; it has depended very largely on the generosity and the initiative of a number of large firms, and one of the reasons for its success has been that, for the student on a sandwich

course, it has been their practice to pay his wages during the whole period of the sandwich course. But my belief is that the spontaneous method has its limitations, and that it has come to a point where its limitations are being felt. It will not enable us to penetrate very much into the smaller firms or into those firms who are not small, but who cannot see the direct advantages to themselves in such a large expenditure. If we are to utilise to the maximum the latent ability that can be usefully transferred to sandwich courses, then we must have a much larger measure of sponsorship by the State and by the local authorities as far as the maintenance of students is concerned. I believe that if that is done generously, there is no reason why there should not be in the very near future a multiplication, by several times, of the number of students of the necessary ability who are transferred from part-time and evening courses to sandwich courses, with both a reduction of wastage and a broadening of the all-round education of the engineer and technologist.

But even if a wider system of scholarships is obtained, the need for co-operation between industry and college will become more necessary than ever.

Dr. Bowden has rightly emphasised the shortcomings of our higher educational institutions, particularly their tendencies to remain aloof from industry and technological education. He has also pointed out the valuable contribution that industry has made in its training schemes.

However, we can by no means be complacent about the demands from industry for technologists. As short a time ago as 1950, the Ministry of Labour Surveys revealed that employers in general were satisfied with the number of engineers and scientists supplied from the colleges. Now, on the other hand, industry finds itself short of about 30% of the technologists it requires. If we are to stimulate both the demand for technologists in all branches of industry and the necessary supply from the colleges, then we must have still closer collaboration between the two sides.

Mr. J. H. Winskill (*Chairman, North-West Region of the Institution*): This is a pleasure as well as a privilege, Mr. Chairman. Those of us who some 40 years ago spent our boyhood days in or near the city of Manchester, were brought up to believe in three things: Christianity, The British Empire and the excellency of The Manchester Tech.!

Tonight we have heard the Principal of this great technical college. It has been said that a lecture, to be really worth while, must be given by a man with a knowledge of his subject, with a gift for words, a ready wit and a missionary zeal — and you certainly have had all those. At one stage in the lecture I wondered whether we were going to start a collection and then looked around for the band and the banners! But it was excellent, Sir, and we have enjoyed it. It is not for me to speak on technology because it is not my job, but let us go away in the same happy way in which you started off, Mr. Lecturer — full of zeal for this work on the education of men in our own profession.

You did mention machine tools. At one time the wife of a machine tool engineer was heard to say to one of her friends that she had come to the conclusion that, whilst it was not necessary that one should be mad in order to be a machine tool engineer, it certainly helped!

A vote of thanks must be like a lady's dress — long enough to cover the subject, but short enough to be interesting and, with those words, I would like to move a warm vote of thanks to our Speaker, Dr. Bowden, for his lecture this evening.

Dr. Bowden : Thank you very much for those very kind words you have just said to me. I would like to ask this question: in 1902 this College was probably the best institution of its kind in the world. In 1903, it was decided that it was not big enough. By 1905, land had been bought ; by 1908, plans had been prepared and people were asking the City Council why nothing was being done about the technical college. In 1912, the plans were approved and they were about to start building when the War came. They were about to start again in 1924. In 1926, a competition was held for new plans. The slump came in 1929. The steelwork was begun in 1939, and the extensions will not be finished until 1957, or 1958, or sometime in the future.

Why was so much done so long ago, but so little has been done for so many years since then ?

The proceedings then terminated.

COMMUNICATIONS

The following written contributions to the discussion have been received since the meeting took place:

From : **Mr. John Wellens** (*Chief Education Officer, Textile Machinery Makers, Ltd.*).

Dr. Bowden has spoken with great frankness on the weakness and inadequacy of our present system of formal education ; it is appropriate that those in industry should be equally frank.

The industrialist might be tempted to fall back on the excuse that if only the universities made the effort and trained more graduate technologists, our problems would be resolved. This would be to close one's eyes to the indisputable fact that many companies do not gainfully employ their existing graduate employees, and this for a very good reason. The traditional industries have geared their employment pattern round the holder of the Higher National Certificate. The five years of apprenticeship match the five years to Higher National Certificate. In course of time, the holder of the Higher National Certificate has become the round peg in the pattern of technological jobs which can be described as round holes. Within this pattern the graduate technologist is a square peg: he does not fit. His employer must admit this fact, not bemoan the difference. For the graduate is different: his academic knowledge is fuller, his practical experience is less and different in character, his attitudes are less rigid, his respect for "authoritative" statements is less and his appreciation of the scientific method is much keener. It does not follow that employment which is suitable for the holder of a Higher National Certificate is suitable for a graduate technologist. In fact, the odds are that it is not. Yet how many firms face up to this fact and consciously plan for their graduate intake ? This lazy attitude of trying to fit the graduate into existing employment patterns is responsible for much dissatisfaction and frustration. Let us admit, therefore, that there are unsatisfactory features (and this is only one of many) within industry itself in this problem of graduate employment.

Let us take warning. Turn to the employment columns of the great national daily newspapers and read the advertisements put in by American companies seeking to draw off British graduates to the U.S.A. Here is an attractive outlet for the frustrated and dissatisfied. What is now a trickle could become a torrent.

From : **C. L. Old** (*Principal, Wolverhampton and Staffordshire College of Technology*).

If I may do so without presumption, I should like both to thank and congratulate Dr. Bowden on a most excellent Paper. It is the best critical survey I have yet met of the

troubled subject of technical education, or would it be more appropriate to refer to the subject as education for a technological age ?

There are so many points one would like to comment upon or enlarge upon, mostly by way of agreement or reinforcement, that quite obviously only a selection can be made.

The opening paragraphs are a most interesting survey of the development of our educational system on the applied side. It is not fundamental to Dr. Bowden's main thesis, but perhaps a little more notice could have been taken of the enormous part that part-time education has played in the past. Without National Certificate types British industry just could not have carried on. This is an historical fact which ought to be recorded. No defence of the system is implied ; on the contrary, the time has come when we cannot rely upon part-time study and the goodwill of students to attend in what is virtually their own leisure time. The Germans have long operated a system whereby nobody above the level of craftsman is trained on a part-time basis. The Berufschulen, at which attendance is compulsory on one day per week for all young people between school leaving age and 18 years, unless they are in some other form of education, provides training at craft levels. The Fachschulen, which train technicians, are organised on a two or three-year full-time basis and, of course, the Technische Hochschulen are four or five years of full-time study. Much the same is true in Russia, France and Holland. Only we are content to put part-time training against full-time training in international industrial competition.

I am sure Dr. Bowden is right in attributing our *malaise* to early training in the schools. Failure on the part of the teacher to teach such things as mathematics, rather than failure on the part of the pupil to learn, is the root of all evil in this connection. Unfortunately for modern Britain, our grammar school system had too early a start. It began to come into existence 400 years ago mainly for a vocational purpose. It succeeded so well that now our whole educational system is geared to it. Even our modern schools are staffed by ex-grammar school pupils and so the tradition goes on into schools where it is alien, and the nation's children are brought up in institutions which are more like Lot's wife than the young man who cried " Excelsior ". They claim that their business is to prepare for life, but they fail to specify in which century that life is to be lived.

From our arts specialists — since we have so many of them — I think the nation has a right to expect some attention to the contemporary world, some consideration to the implications for mankind that the splitting of the atom or the advent of much higher rates of production of consumer goods (commonly known as automation) will hold.

For the rest of Dr. Bowden's Paper, one could get an enormous kick out of underlining his many arresting comparisons. For instance: " In 1951, M.I.T. had 3,000 undergraduates and 2,000 post-graduate students. In the same year (1951) only 270 post-graduate degrees were awarded in the whole of England in all branches of technology ". Or: " Seventy millions (to be spent in five years) may seem to be an enormous sum of money — but — we spend nearly four times as much in advertising *every* year and at least 12 times as much on liquor. The Government is in fact proposing to spend the equivalent of . . . 30 cigarettes a year for every man, woman and child in the country." Dr. Bowden could have quoted the total gambling bill of the country as another possible comparison. Can it be that as a nation we are more concerned with trivialities and that deep down we are dealing with nothing less than moral issues, a lack of desire to put first things first? The ratepayer and taxpayer will gain no satisfaction from Dr. Bowden's figures, for to him expenditure is high. But is it going both nationally and individually on the most important things ?

Just one question: Does Dr. Bowden think the nation has sufficient reserves of mental capacity to provide all the people of the necessary quality that we really need ?

Finally, having had a foretaste of Dr. Bowden's thinking on these things, I for one will look forward with immense pleasure to seeing his book — may it have the desired effect on our national thinking.

***From :* Mr. K. D. Marwaha** (*Graduate Member*).

Dr. Bowden's lecture will no doubt serve to instruct many and stir them out of their complacency. His lucid treatment of the subject deserves praise and admiration.

One aspect of the problem is that there are industrial firms, even today, who are averse to employing a university graduate. This is particularly true in the field of production technology, where higher academic attainments are viewed as superfluous and unnecessary, and where one with years of experience on the shop floor is considered a "better buy". Unless management recognise the importance of reinforcing their production staff by men of the highest merit, they will be depriving industry of the versatility and imaginativeness which it needs so much today.

Secondly, I would like to suggest the setting up of an institute of production technology on the lines of the College of Aeronautics at Cranfield, where fundamental research on metal-cutting, machine tool design and other allied subjects could take place. The work at P.E.R.A. is more of an applied nature and does not embrace the fundamental research I have in mind. This would go a long way in providing the necessary stimulus to this vital branch of technology.

The whole emphasis in the world seems to be on furthering technological education. Let us not deliver a death blow to the studies of Arts and Humanities. If there is not the historian to unravel the past, or the novelist to create drama, or the painter to convey the abstract, or the musician to instil rapture, this life may not be worth living " just for technology ".

" NON-DESTRUCTIVE TESTING AND THE PRODUCTION ENGINEER "

(concluded from page 109)

and continued efforts must be made by all concerned to obtain full and correct information about components under consideration. Despite its limitations, non-destructive testing has much to offer and by continued and constructive collaboration its frontiers will be extended until testing techniques will be evolved of a type not even envisaged at the present time. These techniques will, we hope, be swift, reliable and automatically self checking to such a degree that they can be operated with a minimum of skilled labour and be free from errors due to the human element. Before this is realised, we must face up to many failures and disappointments. Progress along this path will be easier and swifter if all concerned have a clear appreciation of its objectives and incentives. It is hoped that this Paper will have helped in a small way to further this progress.

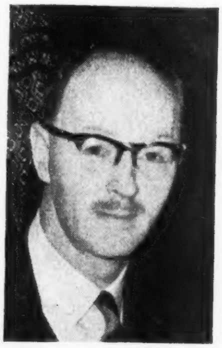
Acknowledgments

In conclusion, it is desired to acknowledge the very great help received from my colleagues in the Non-Destructive Testing Section of the Quality Department at Rolls-Royce, Ltd., and to stress that the opinions here expressed are those personally held by the Writer and do not necessarily represent the official policy of Rolls-Royce, Ltd. Acknowledgments are also due to the Management of Rolls-Royce, Ltd., by whose kind permission this Paper has been published.

NON-DESTRUCTIVE TESTING AND THE PRODUCTION ENGINEER

by W. G. COOK, B.Sc.

Presented to the Derby Section of the Institution on 15th *October,* 1956.



Mr. Cook is a Quality Engineer at Rolls-Royce, Ltd., Derby, in charge of a section engaged in evaluation and development of non-destructive testing methods.

At one time a science master, he was in the Aeronautical Inspection Department stationed at Rolls-Royce, Ltd., from 1940 - 1945, *and joined that Company in* 1950 *as a member of the Process Development Department, transferring to the Quality Department in* 1955.

Mr. Cook is on the Committee of the Non-Destructive Testing Group of the Institute of Physics and is also a member of the Penetrant and Magnetic Panel of the British Welding Research Association.

IN the last decade, the functions of the production engineer have been widened and deepened to an extent which presents a formidable challenge to all members of that profession.

The successful production engineer of today is the leader of a team which embodies a wide range of talents, knowledge and skills. He has at his disposal the advice of numerous experts and specialists, technical and otherwise, whose knowledge ranges from the technical means of production to the estimation of the production potential and the complex problems of capital expenditure likely to be justified by a problematic scale of production. A sound knowledge of industrial phychology and high skill in human relations is also required, since the most difficult problems of all are likely to be those associated with human beings, both at a higher level and in subordinate positions.

The specialists involved thus cover a large number of activities, dealing with machine tools, jigs and fixtures, cutting media, forges, presses, welding equipment, foundry techniques, sand casting, die casting, lost wax casting, shell moulding, copying machines, transfer machines, automatics, machining research, operation planning, machine loading, pre-production planning, statistics and estimation, inspection, as well as other activities too numerous to list.

Formidable as this list may appear, it is likely to be enlarged in the future and, therefore, this is a welcome opportunity to put before a meeting of production engineers an outline of the work being done in the field of non-destructive testing. This is not a new field by any means, but the past few years have seen a tremendous quickening of interest in this work. This has been brought about automatically by the increasingly critical nature of defects in highly

stressed aircraft components of today, highlighted by the Comet disasters, and by the obvious commercial aspects involved.

The Americans have coined a phrase "Non-destructive testing doesn't cost — it pays", and there is no doubt that in its proper application non-destructive testing can act as an invaluable guide to the production engineer by telling him how effectively he is succeeding in his efforts and, in the ultimate circumstance, may be the only means of keeping him in business. Production of itself is meaningless unless the product is suitable for its purpose, is of sufficiently high quality to maintain its position in a competitive field, and unless the production engineer has developed a technique whereby rejectable components are kept to an economic minimum. Here we have the crux of what can be a very thorny and difficult field of contention, where it is vital to consider all aspects of the situation in order to ensure that the flaw detection processes are adequate and realistic.

Before examining this problem in any detail, however, it is necessary to indicate briefly the scope and limitations of the various techniques at present available for non-destructive testing and to stress that in the main it is proposed to deal with flaw detection. At the same time it is proposed to deal with a number of projects of special interest and then to return to the broader problem of how this work is of great value to the production engineer and how, conversely, the production engineer can help by a constructive approach and assist in establishing realistic methods of application.

Available Techniques

1. *Visual Inspection*

The first and perhaps most important technique to be considered is visual inspection. Many of the techniques subsequently mentioned have visual inspection as an integral part of their procedure and in some cases this is the most critical aspect of them, so that some comments on visual inspection are appropriate.

Visual inspection is by far the oldest technique known and can achieve adequate results if properly applied. Low magnification lenses or binoculars (up to 5 or 8X) are frequently used and conditions must be selected so that there is good contrast between defects and the background. Good, glare-free illumination is required, free from dazzle and specular reflections. Operators must be able to work free from physical strain and jigs and supports provided where these ease the problem of handling components.

Careful balance must be maintained between the magnification used and the area an operator is required to examine. Higher magnifications are sometimes used with the assumption that sensitivity is being increased. Any gain is likely to be paid for in decreased reliability and it must be remembered that binocular work on an eight-hour day basis is tedious and exacting. High power binocular microscopes are basically for looking at something already found, not for finding something to look at. Fatigue and boredom are serious problems and considerable skill of diagnosis is called for.

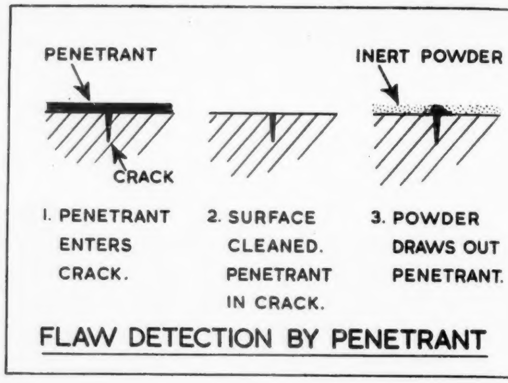


Fig. 1. Principles of penetrants.

2. *Penetrants*

One of the defects of plain visual inspection is often the lack of contrast between the defect and the background. Most penetrants represent an attempt to overcome this lack of contrast and at the same time present a magnified representation of the crack.

The basic procedure is as follows :-

The clean component is covered with the penetrant and time is allowed for the liquid to enter the crack. The surplus is then removed from the surface and the penetrant drawn out by application of a fine film of inert white powder. The colour of the penetrant shows up against the background and the natural seepage from the crack gives a larger area of signal than the original crack. This is shown in Fig. 1.

Although there are penetrants working on a slightly different technique, the three principal types are as follows :-

(a) *Hot Oil and Chalk*

This is one of the earliest and most primitive methods. The component is soaked in hot paraffin and lard oil and then cleaned with sawdust or by washing with detergent solution. The clean, dry component is then dusted with fine, dry chalk. The film of chalk is stained by the oil and gives a magnified indication of the defect. Sometimes a build-up of chalk adhering at the point of seepage gives the same effect.

This process, however, is relatively insensitive to tight cracks, since the contrast of defect indication to background is very low and although the ingredients are relatively cheap the inspection is both slow and uncertain, except for large defects.

(b) *Dye Penetrants*

In order to increase the contrast, dyes, usually red, have been added to the penetrants which have also themselves been modified to work without the application of heat. These new penetrants are generally water emulsifiable, so cleaning is a straightforward

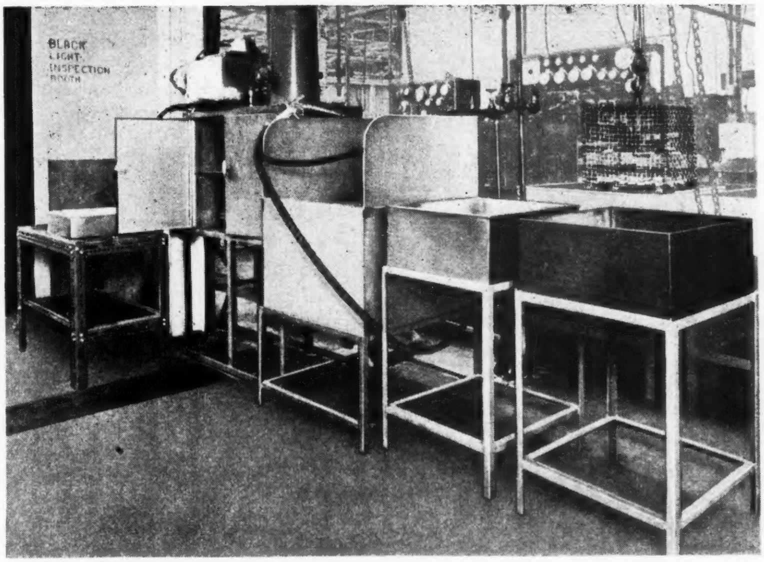


Fig. 2. Pilot plant for penetrants.

water wash, and sensitivity has been further increased by using a developer consisting of a suspension of fine powder in a volatile carrier. Dry powders may be used with some loss of sensitivity.

This technique is much more sensitive than oil and chalk and is particularly suited to castings and also for local application and field work.

(c) *Fluorescent Penetrants*

Still further contrast can be obtained by the use of highly fluorescent additives. These penetrants give bright yellow or green indications against a deep purple background when the component is viewed under "black" light. This type of penetrant represents the greatest sensitivity at present achievable and, in a proper application, the easiest and speediest inspection of all. The process is illustrated in Figs. 2 to 5, which show a pilot plant for processing turbine blades.

The difference between the defect indications and the background (yellow to purple) is probably sufficiently marked for the use of photo-electric cells and filters, in order to make the location of defects automatic by signalling the presence of yellow light. Attempts are being made to make such an automatic inspection device, although preliminary tests indicate that the filtering problems are not easy to overcome, and the system must be capable of detecting a pinpoint source of light.

Penetrants will only indicate defects which are open to the surface. As the sensitivity increases, the problems of diagnosis increase and the selection of a suitable penetrant involves fairly large scale tests to assess these factors. In general, every possible application should be treated on its own merits, since factors other than sensitivity may be involved. These include speed of operation, cost of materials, general workshop conditions and labour available.

Fig. 3. Washing under black light.

Fig. 4. Developing.

Fig. 5. Inspecting under black light.

3. *Etching*

Etching is used extensively for flaw detection, acid, alkaline and electrolytically assisted techniques being used according to the material. The chemical action, of course, removes material with preferential attack in the region of defects and is not completely non-destructive. For components of critical dimensions, only limited etching is possible, as repeated etching may affect components produced to tight limits. As a laboratory technique it is one of the most stringent methods available, although incorrectly used it can produce cracks in otherwise serviceable components.

A good etch is a very searching means of crack detection and may reveal very tight defects likely to be missed by penetrants. This is due to the defects being opened up by the chemical action, whereas prior to etch no cavity for penetration existed. The defects frequently show well against the etched surface, although instances have been found of the etch camouflaging the defect in the grain boundary pattern. Spurious indications can also be very troublesome and cause difficulties in diagnosis. Frequently also binocular microscopes have to be used to assist in detecting very fine cracks and this makes the process very tedious and exacting, as mentioned previously. Visual fatigue and boredom are serious factors and operators have been known to miss glaring cracks whilst searching for minute indications.

Etching is, of course, restricted to defects which reach the surface, although in some cases it removes sufficient material to show defects which were originally beneath the surface.

Considerable care must also be taken to assess the effects of a proposed etching technique on the fatigue and corrosion resistance properties of the components. This may involve a protracted series of lengthy tests.

4. *Anodic Inspection*

This technique is used mainly on forged aluminium alloy components and relies for its effectiveness on the seepage of yellow chromic acid showing against the matt grey background. The process has also a mild etching action and defects which do not seep can also be detected.

This technique only reveals surface defects.

5. *Magnetic Flaw Detection*

This process is applied to magnetisable components and relies on the fact that the defects have a lower permeability than the material itself and consequently distort the magnetic field. At or near the surface, this distortion causes a leakage field which is strong enough to attract fine particles of magnetic material.

The accumulation of particles indicates the defect which may be a crack, slag inclusion, segregation, or

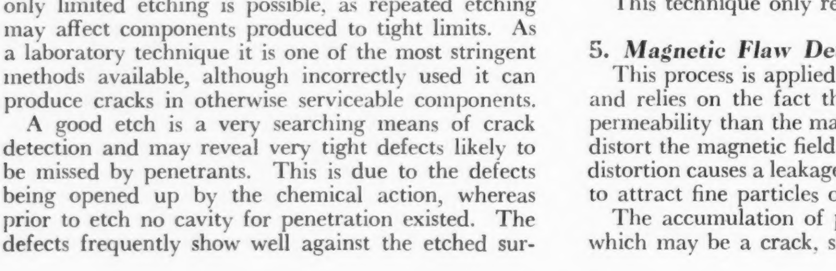


Fig. 6. Principles of magnetic flaw detection.

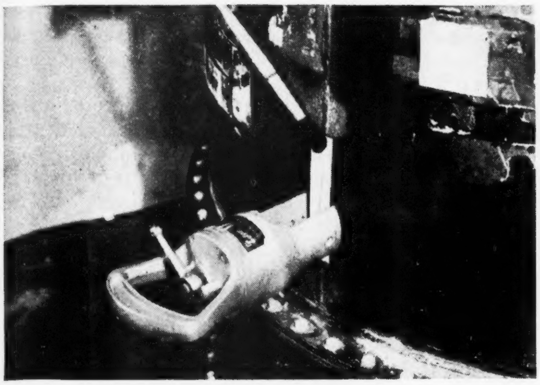


Fig. 7. Magnetic weld inspection.

Fig. 8. Comparison of magnetic and X-ray results on butt welds.

change of structure. Not all of these are necessarily causes for rejection. The basic procedure is illustrated in Fig. 6. Leakage fields are also caused at sharp changes of section, corners, etc. Magnetic crack detection when properly applied is very sensitive, although diagnosis can present considerable trouble. It reveals surface and sub-surface defects according to the procedure but has the following limitations. It is directional to some extent and flaws in or near the direction of the magnetic flow lines are liable to be missed. To inspect a component for flaws in every direction can be slow and for complex shapes involves such a number of handlings and inspections as to make the process difficult to control, particularly when large numbers of components are involved. It is also rather messy and it is not always easy to tell whether the component has been effectively magnetised. The indications are easily wiped off and great care is needed in handling components.

The magnetic powders in use are generally iron oxide suspended in a paraffin and black powder is the most common, although red, yellow, silver and fluorescent varieties are available. These variants are used in attempts to increase the contrast between the flaw indication and the background. Another way of doing this is to paint the background white or use thin, white adhesive tape. The tape technique shows very promising results for weld inspection and the results of tests compare very favourably with X-ray. Fig. 7 shows the procedure and Fig. 8 shows typical results.

A variant of the ink technique is in process of development. In essence this is an attempt to pick up the leakage field at a crack by a coil or probe and feed the signal into electronic equipment which will automatically signal the defect. Equipment is available to do this in fairly simple cases, although the sensitivity achieved to date does not equal that of the ink method. The basic problem is that the leakage field at a crack is very weak and can only be picked up very close to the surface.

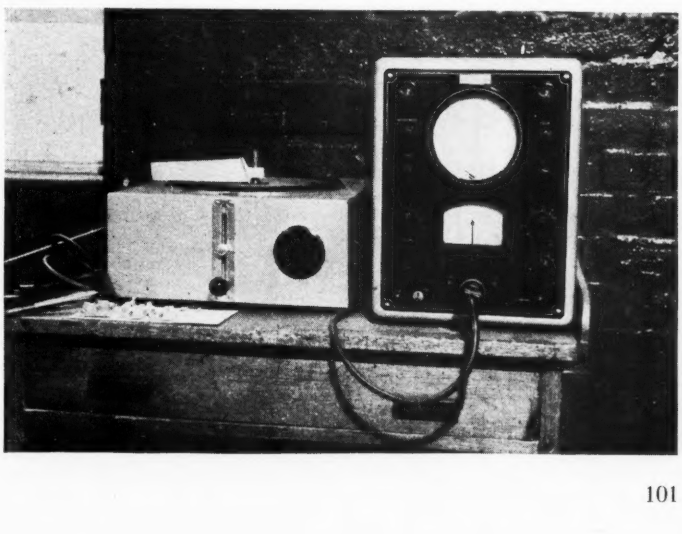
To make probes capable of scanning so close to a surface is not easy. The ink technique, of course, has the advantage that the fluid is in intimate contact and weak, local fields are detectable.

However, insofar as the probe technique offers a means of introducing automatic inspection without the need of viewing, it is a line of development to be pursued energetically and the moderate sensitivity so far achieved should not be allowed to discourage further attempts to improve on this.

6. *Eddy Currents*

In recent years, considerable progress has been made in developing electronic equipment which will detect defects by eddy currents. In principle, the

Fig. 9. Crack detector for light alloy compressor blades.



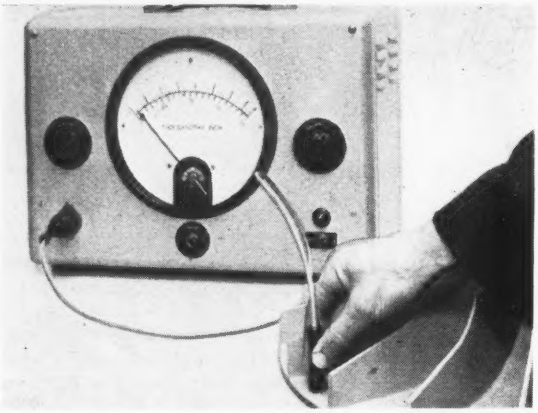


Fig. 10. Measurement of anodic films.

instrument measures the effect on a coil carrying high frequency currents when a metal is introduced into the field of the coil. Devices of this nature have been available for a number of years, but suffered from the defect that they were affected by a number of variables such as dimensions, conductivity, composition and hardness as well as defects, and it was difficult or impossible to resolve the effects of these (and possibly other) variables. Recent work has produced instruments capable of resolving these to some considerable extent and instruments are now available for detecting defects in non-ferrous materials. These instruments are, however, very sensitive to the position of the probe relative to the component so that the application is limited to uniform components, e.g., ground bar, tubes, etc., and a great deal of their value depends upon the severity of the defects they are expected to detect.

The limitations due to geometry are thus considerable for general use, but for the inspection of critical components where considerable expense is justified, their application is likely to be extended very considerably in the next few years. Here again, we have a potential method of inspection without visual inspection.

This offers high speed automatic, foolproof inspection and justifies the expenditure of considerable effort despite the limitations and difficulties encountered. Fig. 9 shows an eddy current machine for detecting cracks in the bores of compressor blades.

By suitable phase analysis it is possible to devise machines based on eddy currents which can measure the thickness of anodic films on light alloy components (see Fig. 10) and a number of measuring devices on the same principle have been developed.

Direct measurement of conductivity is also feasible with this technique and the sorting of mixed materials is often possible by this means (see Fig. 11).

7. *Ultrasonics*

Ultrasonic inspection is a tool of great importance to the production engineer and recent years have seen a great increase in its use. This has been due to the improvement in instruments and the rather slower realisation of its potential by engineers generally. Although attempts are being made to deal with fairly complex sections, it is mainly in the field of large simple shapes that ultrasonics promises to be most useful. The principle of contact scanning is shown in Fig. 12 and Figs. 13 and 14 show applications of this simple principle. The extrusion defects found in the rectangular bar are shown in Fig. 15, the bar having 0.150″ machined off one edge to reveal the defects which are completely internal. Defects found in the round bar are shown up by penetrant in Fig. 16. Fig. 17 shows a fractured bar and Fig. 18 shows pipe located by ultrasonics. An alternative method of finding these defects by ultrasonics is shown in Fig. 19, using an angle probe and a beam of ultrasonic waves echoing up and down along the bar.

Fig. 11. Sorting materials by eddy currents.

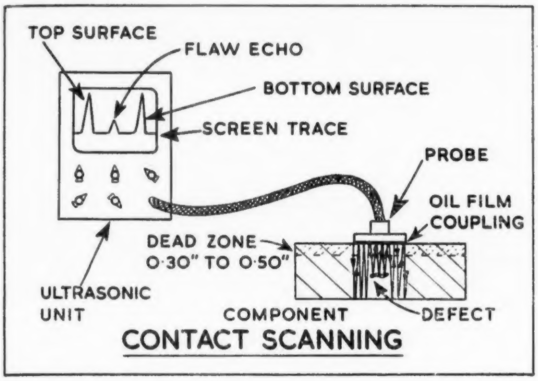


Fig. 12. Principles of contact scanning.

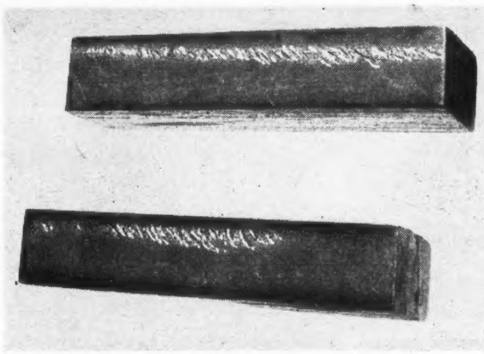


Fig. 15. Internal defects found by ultrasonics in rectangular bar (x 2/3).

Figi. 13. Ultrasonic inspection of rectangular bar.

Fig. 14. Ultrasonic inspection of round bar.

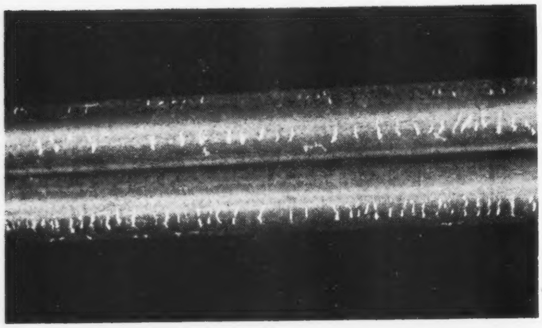
By finding defects in material at the earliest possible stage considerable sums of money are saved and the resources of a modern production unit are not dissipated in efforts to produce components from unsound stock.

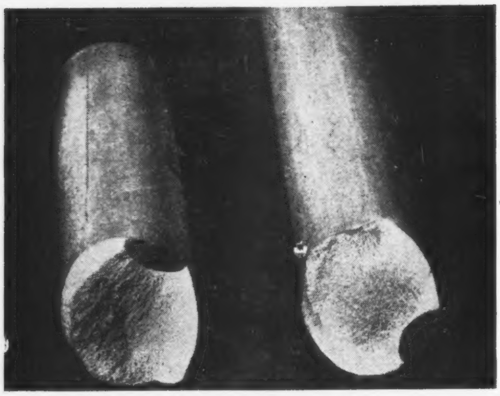
This point is further emphasised by Figs. 20 and 21. These show internal flakes due to hydrogen embrittlement in a 6′ $5\frac{3}{4}$″ billet of S.82 steel. The material was rejected in the billet form.

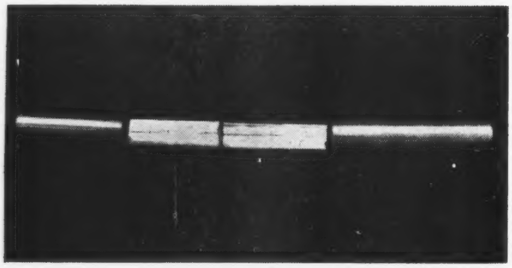
Another gain from the consumer's point of view is that the metal producers become actively interested in the techniques and results obtained, and this can lead to a big improvement in quality.

Ultrasonic inspection by contact scanning has a number of disadvantages. Apart from the question of awkward shapes already mentioned, it is inclined to be messy and unreliable when scanning large areas. The probes tend to wear away, but the most important feature is the inability to be sure that the operator has fully covered the component. Most modern sets have single probes combining the duties of transmitter and receiver, although some sets have double probes, but even with single probes difficulties are encountered which can be best described as "finger trouble".

In an attempt to overcome these difficulties, the method of immersion scanning has been developed. The principle is basically the same, but the coupling between the transmitter and the component is effected by a layer of water instead of a film of oil. The basic idea is shown in Fig. 22 and a simple tank working on this principle is shown in Figs. 23 and 24. This technique ensures complete scanning of suitable areas and this can be made fully automatic with monitoring to indicate defects. A great deal of work has been done in the States on this type of equipment, chiefly on simple shapes such as light alloy slabs for aircraft spars, etc. Steel discs and circular forgings are also being examined in much the same way.







Figs. 16 - 19 (*reading from top down*).

Fig. 16. Cracks in round bar found by ultrasonics and shown by penetrant.

Fig. 17. Fracture of round bar showing defect (x 1).

Fig. 18. Internal pipe found by ultrasonics (x $\frac{1}{4}$)

Fig. 19. Ultrasonic inspection of bar by angle probe.

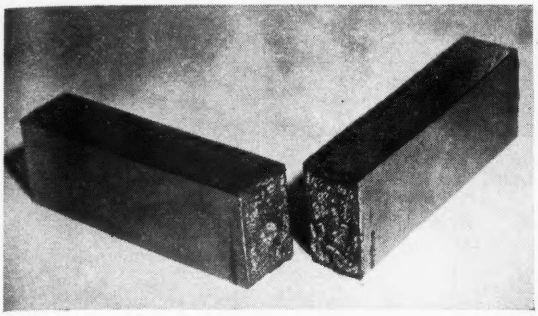


Fig. 20. Axial flake in S.82 steel found by ultrasonics (x ½).

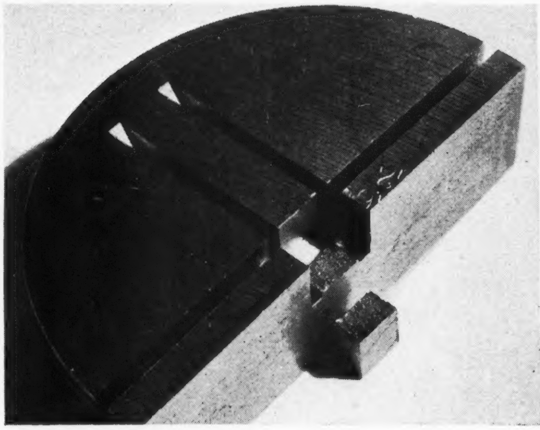


Fig. 21. Transverse flake in steel found by ultrasonics (x ½).

The tank illustrated in Fig. 23 has produced some valuable results. Typical defects located inside steel forgings are shown in Figs. 25 to 28. The ability to assess the depth of these flaws as well as their radius enabled predictions to be made as to whether they would fall across or in the finished section.

Only in this case can the forging be rejected, since defects outside the finished section will machine away without being noticed.

In addition to the large saving in machining time effected in these cases, some of these components were in short supply and their early rejection enabled replacements to be progressed and thus reduce delays in the engine programme.

There appears to be a big future for this type of work and it is fairly safe to predict that the ultrasonic inspection of all heavy rotating members of aero engines will soon be mandatory. The equipment illustrated has been used to anticipate this requirement.

The limitations of this type of equipment are, firstly, its inability to cope with complex shapes due to difficulties of interpretation and, secondly, that it cannot readily deal with sections below about 0.500". These two conditions combined make the use of this type of ultrasonics on finished aircraft components rather small. The use of improved crystals and circuitry, however, may help to reduce the section capable of being inspected by echo techniques. In addition, two other ultrasonic techniques are now available: inspection by surface waves and inspection by transmission techniques. Under suitable conditions ultrasonic waves can be generated which skim the surface of the component and detect cracks by echo. Echoes are also produced by sharp corners and radii so the possible applications are limited. Fig. 29 shows a surface wave crystal in use.

The transmission technique consists of sending a continuous beam of sound through a component, with internal reflections if necessary, and measuring the intensity of the emergent sound beam. The presence of a defect causes a sharp fall in intensity.

This seems a very good tool for special investigation, the main difficulty being to ensure good, consistent coupling at both transmitting and receiving probes and to maintain constant geometrical relationship by firm jigging. On a production basis this presents great difficulties and the use of immersion techniques seems the only answer. This, however, remains to be established. Fig. 30 shows an instrument working on this principle.

8. *X-Ray*

Radiography is well established as a means of inspecting the interior of components, although as a means of crack detection it must be rated very low. Basically, this is because radiography is capable of detecting difference in X-ray path, generally of the order of 2% of the section under examination, although much better sensitivities are claimed in special circumstances. Cracks very rarely occupy this proportion of the section unless orientated exactly in line with the beam. For example, X-ray is incapable of revealing defects similar to those shown in Figs. 25 to 28.

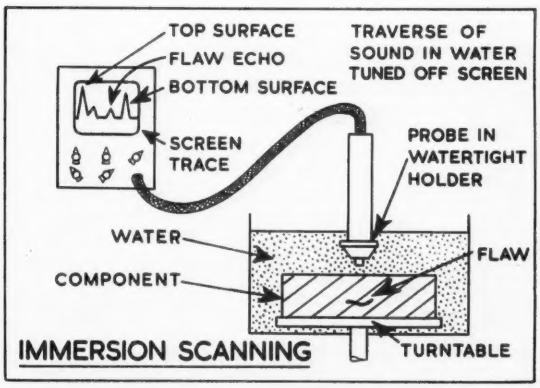


Fig. 22. Principles of immersion testing.

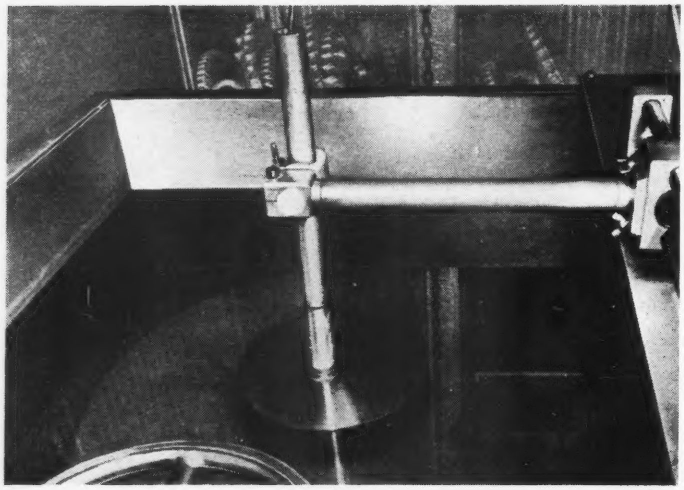


Fig. 23. Ultrasonic immersion tank.

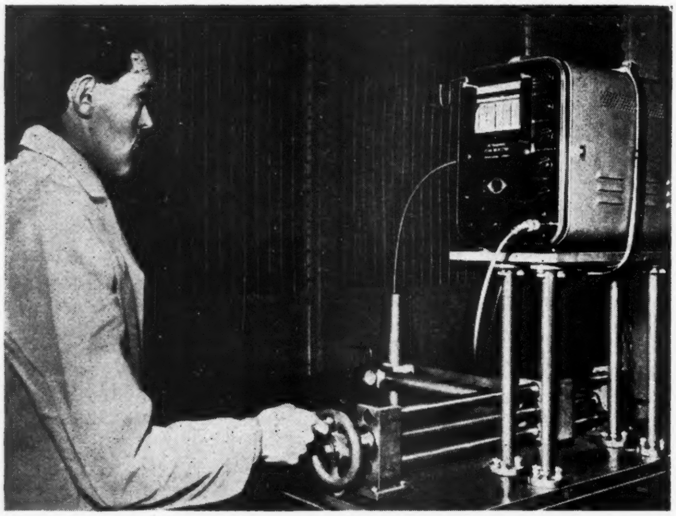


Fig. 24. Ultrasonic immersion tank in use.

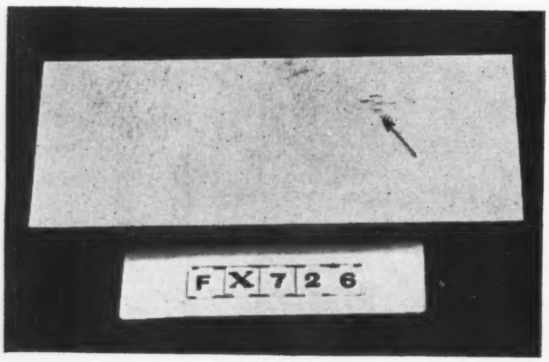


Fig. 25. Defect found by immersion testing (x $\frac{1}{2}$).

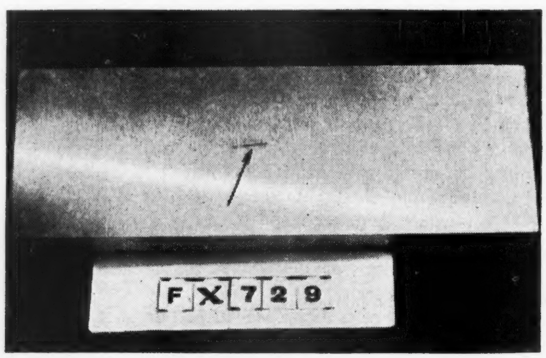


Fig. 26. Defects found by immersion scanning (x $\frac{1}{2}$).

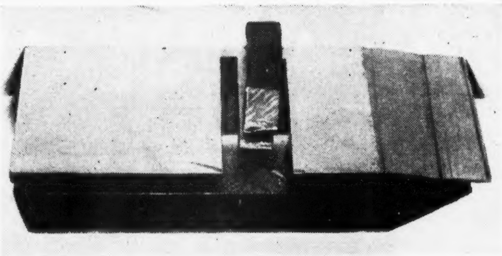


Fig. 27. Disc cut and fractured to show defect (x ½).

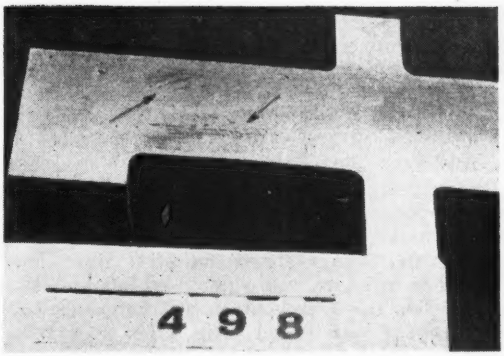


Fig. 28. Defects in forging found by immersion testing (x ½).

Thus the main function of X-ray is to detect internal unsoundness of a relatively gross order, and instances can be found of designers calling for X-ray examination with the mistaken idea that they are instituting an effective inspection for flaws.

By replacing the photographic plate by a fluorescent screen, it is possible to inspect components much more cheaply and more rapidly. Unfortunately there is a serious loss of sensitivity and fluoroscopy can only be used to detect gross defects. It can, however, be very effective in certain applications, e.g., checking inaccessible assemblies such as radio valves, electric circuits, etc., for completeness.

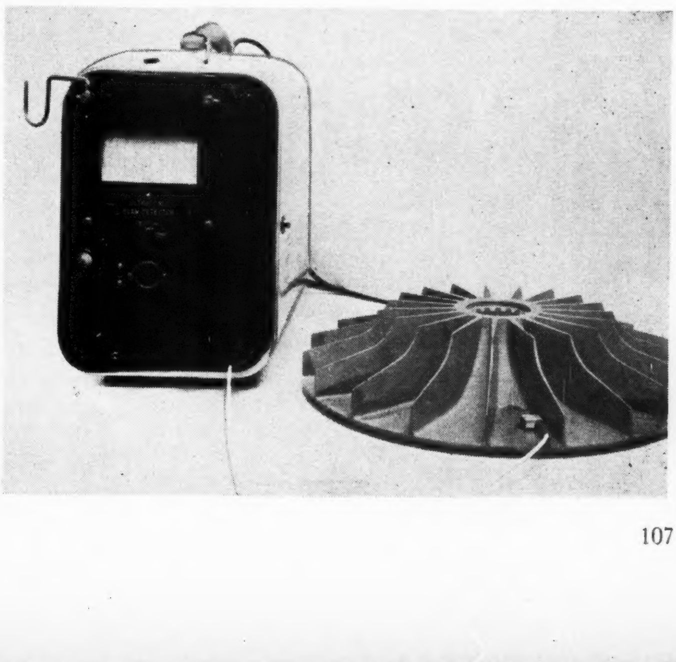
General Observations

The foregoing notes give a brief outline of the scope of the work going on in the various fields of non-destructive testing. The techniques themselves are very varied, but anyone working on them will encounter difficulties and problems which are common to them all.

Standards

One problem is that of standards. A great deal of confusion frequently exists here and the standard of serviceability is often only vaguely defined. Truth is said to be at the bottom of a well and this is certainly a deep one. Designers, quality engineers and inspectors often err on the side of safety as they are bound to do, especially if they are dealing with components about which little service experience is known. Production engineers see the problem a little differently and have been known to express strong opinions about standards which appear too stringent. It is, however, important to realise that the finding of defects by a particular technique and the establishment of standards are two distinct processes. Admittedly, a new technique of inspection may reveal defects hitherto unseen and so affect the standard of acceptance, which has always to be assessed in the light of as full a knowledge as can be obtained and calls for close liaison between Production, Service and Development Departments. A great deal of work is involved in correlating standards by two different techniques and improvement in flaw detection techniques almost always makes the problem more difficult; this difficulty is sometimes the reason for rejecting a new technique, perhaps unwisely.

Fig. 29. Inspection by ultrasonic surface waves.



Attitude to Inspection

A second problem is a rather broader one and that is the attitude of mind towards inspection. This attitude is shown at its worst by those who regard inspection as a necessary evil, not to be encouraged unduly.

Vast sums of money have been spent on the means of production ; multi-spindle machines, transfer machines, bigger and better forges and presses, automatic multiple copying machines, high speed tools, automatic finishing machines and so on have been produced to speed up production. Whilst the means of production have vastly increased, very little consideration or effort has been made in the past to speed up the means of flaw detection. It is therefore no wonder that management suddenly find that it is costing more to inspect some components than to produce them. The checking of dimensions has been mechanised in some cases. Admittedly the problems are of a different order of difficulty. To make, say, a multiple head copying milling cutter is simple, compared with the problem of designing an instrument capable of showing the discrimination and sensitivity of the human eye over the wide range of indications by which defects can show themselves. Nevertheless, unless determined efforts are made to solve this problem the inspection of components is likely to take an increasing proportion of the overall time to produce a component. In order to reduce the adverse ratio of production to inspection time, it is evident that considerable time and money must be spent to apply the resources of science and electronics to produce instruments capable of replacing or supplementing the human eye.

The Problem of Numbers

The third problem facing the worker in this field is that of numbers. This is encountered in three rather different ways.

The first is fairly simple, although it is surprising how many workers in this field have failed to realise it. On any production line flaws and defects occur under very variable conditions and the causes may range from individual batch or component troubles to complete changes of technique. It is difficult to be sure beforehand that a given batch is even typical, so it is inevitable that considerable numbers of components need to be processed to arrive at a correct overall picture and so form a reliable assessment.

Some workers in this field are prone to producing odd specimens (usually with a freak defect) and inviting the unwary enthusiast to try his hand. The results are usually misleading and it is imperative to work on as large a number as possible, to use a fairly large number in a trial run to learn the pitfalls and establish a working standard and then to follow this with a sizeable pre-production run. The findings should be assessed by all means available, using other non-destructive techniques as well as destructive tests, to ensure that realistic conclusions are obtained. The numbers involved will vary according to the type of component. To give a concrete illustration, a recent test on a certain critical component involved over 8,000 pieces before production inspection was instituted. In an exercise on precision castings some 300 were inspected to verify the technique and over 3,000 for trial purposes. On large castings, smaller numbers may be sufficient to give an answer, since each casting can form a number of exercises in itself.

The Problem of High Standards of Reliability

The second problem of numbers is more difficult, particularly on aero engine work. This problem is basically that of improving on a process which has already achieved a reliability of, say, 99.9+%. Again take a concrete illustration. A component is being inspected at a rate of 50,000 a week with a reliability of, say, one defective component missed per 10,000 inspected. This is a high order of performance by any standard, but nevertheless represents five components per week which must be rejected. The defects missed are found on a second inspection, but it is obviously desirable to find a foolproof first inspec-

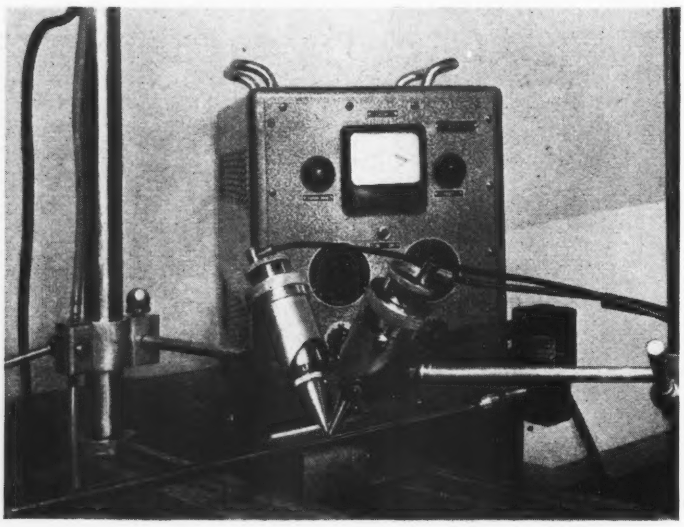


Fig. 30. Inspection by ultrasonic transmission.

tion technique. To do this entails a very large scale effort indeed and may necessitate running two inspection processes side by side on a production line, with alarming results on output. Of course, before this was embarked upon, smaller trials to assess potentialities would have to be successfully carried out, but these figures illustrate the size of the problem facing the aeronautical engineer today. Whether any process involving human perception and skills can substantially improve on 99.9% reliability is itself doubtful, and the field for reliable automatic inspection devices is wide open.

Detection of Rare Defects in Critical Components

The third problem is that of finding an inspection technique for a defect which is rare although it is critical. In this case, also, one is faced with a very prolonged programme of testing and evaluation, and considerable patience is needed in recording and analysing results. Frequently much of the evidence is negative. To take a concrete example ; say 500 forgings are inspected by a new ultrasonic technique and passed as free from defects. These have to be followed through and out of these, 490 are finally passed as satisfactory, and 10 are scrapped for reasons other than defects. The results of this test are largely negative. It is only when a defective forging is predicted and confirmed, or a forging passed by ultrasonics is rejected as cracked at final inspection, that positive evidence can be obtained. The infrequency of internal cracks in some forgings leads to very long tests to attempt to prove a point. The diversion of such a large quantity of forgings inevitably has some effect on the progress of production items, and it is clearly essential that co-operation with production personnel is maintained. For an exercise of this scale to be effectively carried out and follow-through checks to be made, it is unavoidable that many people are involved and the problem is made much easier if the production engineers concerned appreciate the broad outlines and purpose of the effort.

Returning to the 500 forgings, there is a major pitfall to avoid. The conclusions on the ultrasonic tests assume that checks have been made to prove the validity of the procedure. But it must be borne in mind that 500 good forgings could have been passed good by any technique, for that matter with the ultrasonic set switched off. This point is not so ridiculous as it seems. Inspection techniques of this sort have been known and since they are equally effective in passing good and bad components, so long as the components are good everyone is happy in their ignorance. It may be only when defects are found by some other way that the inadequacy of the technique is realised. Where defects are very rare the problem has always to be posed as to whether the absence of defects is genuine, or whether they are present but not found by the technique in use.

This brings us to the final arbiter of all things good or bad — the engine itself. All standards are ultimately set by the engine — a very hard taskmaster. It shows neither discretion nor consideration, although it frequently shows disconcerting unpredictabilities. As powers and performances advance and stresses rise, new standards are needed and old standards, built up over years, may be scrapped overnight. The production engineer is faced with making new and more complicated complexities and the inspector and quality engineer have to find ways and means of testing them to reasonable standards. It is only by a full understanding of each other's problems that progress can be achieved and the future assured.

By way of recapitulation, it is worthwhile to look at the flaw detection processes in a functional capacity and in this respect they serve in three distinct fields.

The first is the inspection of raw materials and part processed components. Here the main objective is to prevent the production engineer applying his efforts to unsound stock. In many cases, the traditional laboratory metallurgical procedures are very inefficient for flaw detection and they are increasingly being supplemented by the use of ultrasonics, penetrants, eddy current and other techniques. Inspection at this stage offers great saving in wasted machining time and also provides a very valuable control in that it prevents the pipe line from being filled with unsound material. This latter aspect is sometimes not appreciated until it is too late, and production schedules and programmes are disrupted when components are rejected in the finished state.

The second function is that of detecting defects in finished components. Here, by far the greatest effort is expended and the defects thrown up may be either due to unsoundness of the original stock, or due to poor manufacturing technique. Here again, a valuable guide is available to the alert production engineer to enable him to find the cause of the trouble and to remedy it insofar as it is within his power to do so. Other non-destructive tests are frequently carried out at this stage such as pressure testing, rig testing and the like but these are outside the scope of this Paper.

The third important function is to test the components during repair. This is a field with special problems of its own, since the defects encountered are caused by running and are consequently very different from manufacturing defects in new components. Repair components are often difficult to deal with owing to oxidation, the need for removing paints and enamels, and cleaning generally. Fine fatigue cracks which may be under compression when the component is static can also be very troublesome and call for the most stringent inspection techniques. Whilst the defects found can be valuable to the production engineer, the majority prove to be a guide to the designer and development engineer. Nevertheless, the production engineer has to study any defects found at repair with the greatest care, since the discovery of defects due to faulty manufacture invariably has very serious repercussions and may call for remedial action on a very expensive scale, perhaps necessitating the withdrawal from service of suspect items.

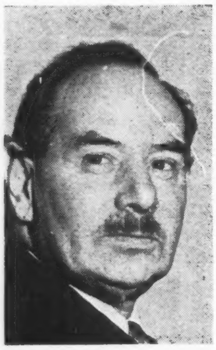
The main conclusion to be reached from all this work is that non-destructive testing is an essential guide to the production engineer, and that determined

(*Concluded on page* 96)

THE PNEUMATIC GAUGING TECHNIQUE IN ITS APPLICATION TO DIMENSIONAL MEASUREMENT

by J. C. EVANS, B.Sc., Ph.D.

(A Communication from the National Physical Laboratory)



Dr. J. C. Evans is a graduate of the University of Wales. He was a Viriamu Jones Research student of University College, Cardiff where he did research in Physics and obtained a Ph.D. degree. He joined the Metrology Division of the National Physical Laboratory in 1926 and worked on the fundamental metrology of the physical quantities, length, mass, time, pressure, etc. He transferred to engineering metrology in 1939 and from 1942 to 1946 was Assistant Director of Gauges and Measuring Instruments in the Machine Tool Control of the Ministry of Supply. At the end of the War, he returned to NPL and took charge of a section newly created to do research in automatic control. He re-joined his old Division in 1950 when he took charge of the engineering side. He first became interested in pneumatic gauging during the War and, realising its potentialities for industrial measurement and control, he has studied and made researches into the technique which have led to the development of several new instruments.

IN discussing with physicists and engineers the application of pneumatic gauging to their problems in linear measurement, it invariably emerges that those who have not already used the technique are at a loss to know how to set about it. What pressure should be used, what type of jet would be suitable, what would be the best arrangement to secure the sensitivity required, and so on; these are the questions asked, and that they should be asked points to the lack of published information on such practical matters. It is the object of the present Paper to try to remedy this situation.

The Paper will, however, deal only with that type of pneumatic gauging in which a displacement or a change of size is determined by measuring the change of pressure which it is made to produce.(1,2,3,4,5,6) This is the scheme most commonly used in this country, and it needs to be distinguished from an alternative technique, used extensively in America, in which the flow of air is measured.(7) It has the advantage that several different methods are available for measuring the change of pressure, so that indicating or recording instruments may be used; also, when required, pneumatic amplification may be introduced to raise the pressure change to a power level adequate to serve as a control signal for automation.

Theoretical Considerations

The principle of the pneumatic gauging technique to be discussed can best be described by reference to Fig. 1 (a). Air from a constant pressure source is supplied first to an orifice O_c and thence to an orifice O_m through which it escapes to the atmosphere.

Let P be the pressure upstream of the first orifice
p the pressure between the two orifices
both being measured with reference to the atmospheric pressure as datum.

The relation between p and P will depend upon the relative sizes of the orifices, and the limiting values for p are obviously P, when the second orifice is closed completely, and zero (atmospheric pressure) when this orifice is removed.

Let C be the geometrical area of O_c
M the geometrical area of O_m
Then, if P and C are kept unchanged whilst M is varied, the relation between the dimensionless quantities $\frac{p}{P}$ and $\frac{M}{C}$ has the general form shown in Fig. 1 (b). This relation has been investigated experimentally at the National Physical Laboratory for several values of the constant pressure P within the range 2 to 75 lb./in.^{2}* and some of the curves obtained are reproduced in Fig. 2. This work will be described in more detail in a Paper to be published later, but some of the conclusions drawn from it are summarised below.

Examination of any one of the curves obtained when $\frac{p}{P}$ is plotted against $\frac{M}{C}$ shows that within the range

$$0.6 \quad < \quad \frac{p}{P} \quad < \quad 0.8$$

the curve approximates very closely to a straight line, the equation to which may be written in the form

$$\frac{p}{P} \quad = \quad A \quad - \quad b\frac{M}{C} \qquad (1)$$

Inspection of the family of curves shows that A, the intercept on the $\frac{p}{P}$ axis, is surprisingly constant over the range of pressures covered by the experiments, and for practical purposes the value $A = 1.10$ may be adopted for any value of P which is likely to be used. The slope of the straight portion of the curve is not, however, independent of P: its numerical value decreases as P increases and the limiting values are approximately

$$b = 0.58 \text{ when } P = 2 \text{ lb./in.}^2$$
$$b = 0.41 \text{ when } P = 75 \text{ lb./in.}^2$$

Certain important practical relationships can be drawn immediately from the foregoing.

1. *Range of Linear Measurement*

The linear part of the curve being represented, within the range $0.6 < \frac{p}{P} < 0.8$, by

$$\frac{p}{P} \quad = \quad 1.10 \quad - \quad b\,\frac{M}{C}$$

let M_n represent the minimim value of M
and let M_x represent the maximum value of M within the linear range (see Fig. 3).

* 1 inch = 2.54 cm. 1 lb. = 453.6 g. 10 lb./in.^{2} = 0.70 kg./cm.^{2}

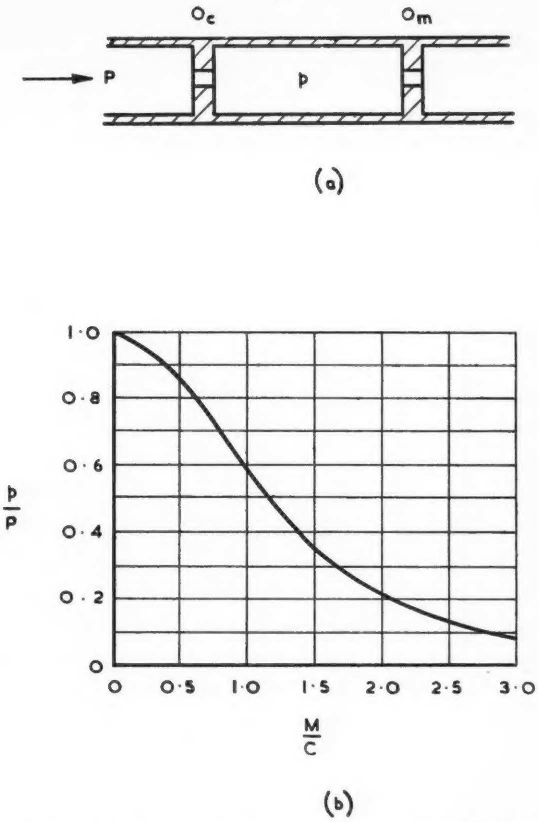


Fig. 1. Principle of the pneumatic gauging technique.

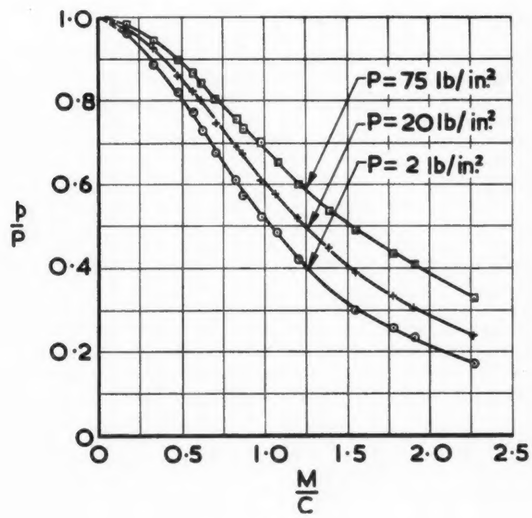


Fig. 2. Experimentally obtained characteristics.

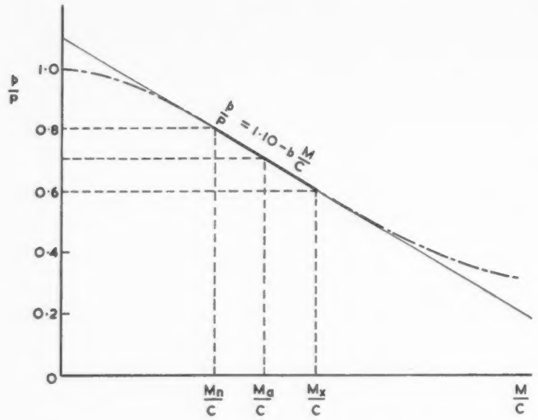


Fig. 3. Range of linear measurement.

Then $b\dfrac{M_n}{C} = 1.10 - 0.8 = 0.3$

$b\dfrac{M_x}{C} = 1.10 - 0.6 = 0.5$

so that $\dfrac{M_x}{M_n} = \dfrac{5}{3}$

and $\dfrac{M_x - M_n}{M_x + M_n} = \dfrac{1}{4}$

If M_a = average value of $M = \frac{1}{2}\ (M_x + M_n)$

$$M_x - M_n = \tfrac{1}{2}\, M_a \qquad (2)$$

so that the linear range of M is 50% of the average value, a result which is independent of the value of P.

(NOTE. The choice of the limits 0.6 and 0.8 for $\frac{p}{P}$ may be criticised as being too severe. Their use ensures linearity within 1%, but where some loss of linearity at the extremes is acceptable, they may be opened up to

$$0.55 < \frac{p}{P} < 0.85$$

or even to

$$0.5 < \frac{p}{P} < 0.9$$

If the first of these alternatives is adopted, the range becomes $\frac{3}{4}\, M_a$.

The theoretical conditions which must be satisfied to obtain linearity between p and M when P and C are constant have been described. To obtain linearity between p and the dimension being measured it is, of course, necessary also that change of the dimension should produce a proportional change in M, and the measuring head must be designed accordingly.

This may be exemplified by considering the action of a simple jet J (Fig. 4) impinging on a surface S whose displacements are to be measured. Escapement of the air from the jet may be considered to be determined by the area of the curved surface of the cylinder of diameter D and length L, and under appropriate conditions, which will be discussed later (p. 117),

$$M = k\,\pi\,DL$$

where k is a numerical constant. Displacement of the surface thus produces proportional change in M and linearity between p and L is realised.

2. *Pneumatic Sensitivity*

By differentiating equation (1), the pneumatic sensitivity, $\frac{dp}{dM}$, over the linear part of the characteristic is obtained. Thus

$$\frac{dp}{dM} = -\,b\,\frac{P}{C} \qquad (3)$$

It will be seen to depend directly on P. It also depends indirectly on P, since $b = f\,(P)$; from the design point of view, however, this qualification of the sensitivity is not so significant as the direct variation with pressure.

If now C is chosen so that when M has its average value p is at the mid-point of the linear range, i.e. $p = 0.7\,P$,

$$0.7 = 1.10 - b\,\frac{M_a}{C}$$

or $$\frac{b}{C} = \frac{0.40}{M_a}$$

and, from (3), the penumatic sensitivity may be stated as

$$\frac{dp}{dM} = -\,0.40\,\frac{P}{M_a} \qquad (4)$$

3. *Overall Magnification*

The overall magnification of a pneumatic gauge, i.e. the ratio of the linear movement of the pointer or index of the final indicating device to the change

of linear dimension L which produces it, will depend also on (a) the rate of change of M with L and (b) the sensitivity of the pressure measuring device i.e. the rate of change with p of the reading R of this device.

Thus the overall magnification is given by

$$\frac{dR}{dL} = \frac{dR}{dM} \cdot \frac{dM}{dL}$$

$$\text{i.e.} \quad \frac{dR}{dL} = \frac{dR}{dp} \cdot \frac{dp}{dM} \cdot \frac{dM}{dL} \tag{5}$$

4. *Design Equations*

The equations obtained in the preceding sections, viz.:

Linear range (1 % linearity) $= \frac{1}{2}\ M_a$

Pneumatic sensitivity $= 0.40 \dfrac{P}{M_a}$ (numerically)

Overall magnification

$$\frac{dR}{dL} = \frac{dR}{dp} \cdot \frac{dp}{dM} \cdot \frac{dM}{dL}$$

provide a basis for calculation when designing a pneumatic gauge to suit any particular problem.

Their use may be illustrated by referring again to the simple jet (Fig. 4).

$$M = k\,\pi\,DL$$

$$\text{and} \quad M_a = k\,\pi\,DL_a$$

where L_a is the average separation of jet and surface.

If the pressures P and p are measured by means of a water column and if H and h are the corresponding lengths of column,

$$P = \rho\, gH$$

$$p = \rho\, gh$$

where ρ is the density of the water and g the acceleration due to gravity.

$$\text{Then} \quad \frac{dR}{dp} = \frac{dh}{dp} = \frac{1}{\rho\ g}$$

$$\text{and} \quad \frac{dp}{dM} = -0.40\,\frac{P}{M_a} = -0.40\,\frac{\rho\, gH}{k\pi DL_a}$$

$$\text{Also,} \quad \frac{dM}{dL} = k\pi D$$

so that the overall magnification is

$$\frac{dh}{dL} = \frac{1}{\rho g} \times -0.40\,\frac{\rho\, gH}{k\pi DL_a} \times k\pi D$$

$$\text{i.e.} \quad \frac{dh}{dL} = -0.40\frac{H}{L_a} = 0.40\,\frac{H}{L_a} \ \text{numerically}$$

The range for 1 % linearity is $\frac{1}{2}\ L_a$

Thus, if the required linear range of measurement is 0.001 in. and a constant pressure P equal to 20 inches of water is to be used,

$$L_a = 0.002 \quad \text{and} \quad H = 20$$

Then the overall magnification, i.e. ratio of the movement of the meniscus of the water column to the corresponding displacement of the surface, will be

$$\frac{dh}{dL} = 0.40 \times \frac{20}{0.002}$$

$$= 4{,}000$$

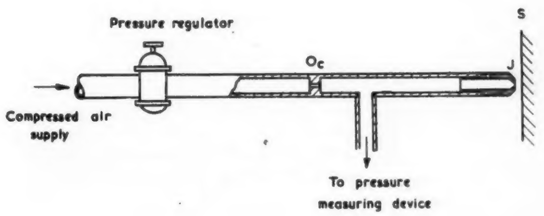
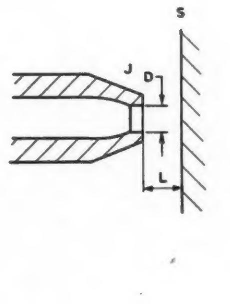


Fig. 4. Simple jet impinging on a surface.



Alternatively, with the same jet arrangement, and with P made 40 lb./in.², let a Bourdon gauge be used to measure p. Let the (uniform) scale length of the gauge for the range 0 to 40 lb./in.² be 20 inches and let the average separation of jet and surface again be $L_a = 0.002$ in.

Then the overall magnification is

$$\frac{dR}{dL} = \frac{dR}{dp} \cdot \frac{dp}{dM} \cdot \frac{dM}{dL}$$

$$= \frac{20}{40} \times 0.40 \frac{40}{k\pi D \times 0.002} \times k\pi D$$

$$= 4{,}000$$

The sensitivity is thus the same as when the pressure was measured by means of a water manometer. In general, if P is the constant pressure used and λ is the length of uniform scale on the pressure measuring device corresponding to the pressure range $O - P$, then the overall magnification is

$$\frac{dR}{dL} = 0.40 \frac{\lambda}{L_a}$$

Thus, although, by using a larger value of P, the pneumatic sensitivity may be increased, there will generally be little gain, for practical reasons, in the overall magnification. It follows that the only effective method of increasing the overall magnification is to reduce the average separation between the jet and the surface, this reduction being, of course, accompanied by a corresponding reduction in C in order to preserve the relationship $p = 0.7P$ when $M = M_a$.

This need to reduce the separation in order to gain high sensitivity is the chief disadvantage of the pneumatic technique. One way of overcoming the difficulty is to use two stages of amplification, both pneumatic. A two-stage comparator of overall magnification 100,000, in which the average clearance at the measuring head was 0.004 in., was designed at NPL some years ago.[6]

5. *Speed of Response*

The speed of response of a pneumatic measuring device, although not very different from that of measuring systems involving high mechanical amplification, is considerably slower than that of electrical or electronic devices. The pneumatic technique is, therefore, quite unsuitable for rapid dynamic measurements, that is for measurements for which a time constant of less than 0.1 second is essential. For continuous measurements required to give time-average values the pneumatic gauge is, however, quite suitable, the integration resulting from the relatively long time constant being an advantage. Indeed, in many applications to continuous measurement it is useful, and easy, to increase the time constant by adding suitable pneumatic networks.

The reason for this tardiness of the air gauge is easy to see. Between the measuring head and the control orifice (Fig. 4) there exists a closed volume, to which must be added the volume associated with the device used to measure p. A dimensional change at the measuring head, i.e. a displacement of the surface S, produces a change in p because it alters the rate of flow of air through the control orifice O_c. The time needed to establish the new value of p depends on the volume mentioned and on the rate of flow. The latter, in turn, depends on the value of P and the size of the control orifice. To quicken the response, therefore, the volume must be reduced and the rate of flow increased. Since the overall magnification of the system depends on C, being inversely proportional to it, the speed of response will fall as the magnification is increased. So, when seeking high sensitivity, one must accept slow response.

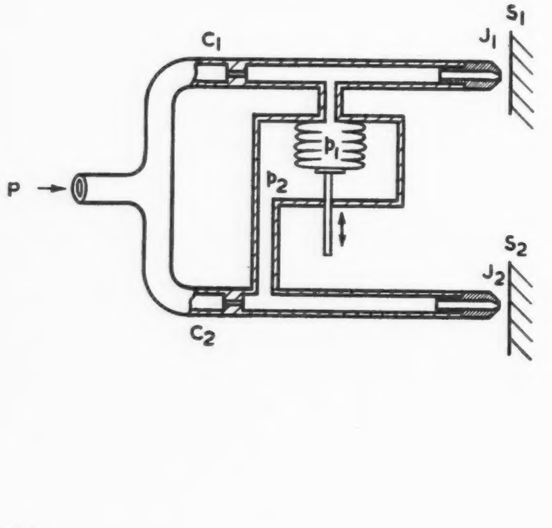


Fig. 5. An illustration of the Wheatstone bridge principle.

Practical Considerations

1. *Air Supply*

In most cases, an air supply line at adequate pressure and providing an amply sufficient flow is available in the factory or workshop, but if not a suitable compressor can be purchased. It is important that the air supplied to the pneumatic gauge should be clean and dry, but the availability of commercial filters makes this requirement easy to meet.

To provide the constant pressure P a pressure regulating device must be fitted, and it may be necessary to precede this with a simple pressure reducing valve. For low pressures, of the order of 1 lb./in.^{2}, a water bubble-tank is a suitable pressure regulator. In this device, the incoming air is led into a tube whose open end is 20 in. or, in the case of the larger tank, 40 in. below the water surface, and the air flow is adjusted by a control valve so that the air bubbles break regularly from the bottom of the tube at a suitable rate. Alternatively, a diaphragm operated mechanical pressure regulator, which automatically keeps the pressure constant irrespective of the flow, may be used. These regulators are made for a wide range of pressures and will provide regulation within 1 %; that is to say, the outgoing pressure will show no variation exceeding 1 % of the variation in the input pressure. For special projects, or when the air supply line is subject to large variations of load so that its pressure fluctuates widely, it may be necessary to fit two pressure regulators in series. A bellows-operated or Bourdon type pressure gauge should be provided to show the actual value of the pressure supplied to the pneumatic gauge.

The constant pressure used in pneumatic gauging may have any value from twenty inches of water or less to 40 lb./in.^{2} or more and the choice lies with the designer. The use of a high pressure reduces the time-constant, which may be useful in some applications; it increases the pneumatic sensitivity, but as the overall magnification depends also on the means for measuring p (see p. 112) this may not be as useful as it might seem at first sight. On the practical side, it has a useful scouring action; thus, when work is being measured on a machine tool during manufacture, a high pressure at the measuring head removes swarf and coolant. The advantages conferred by employing low pressures are that high overall magnification can be obtained by using a simple device, i.e. a water column, to measure p and, second, that delicate objects can be gauged without damage. This latter advantage is, of course, due to the fact that a low pressure pneumatic gauge exerts very little force on the object being measured. A measurement made at NPL showed that the force exerted on a surface by a jet of air at a pressure of 10 lb./in.^{2} issuing from an orifice of diameter 0.040 in. placed 0.001 in. from the surface was 0.2 oz. wt.[3]. If the pressure were reduced to 1 lb./in.^{2}, the force would be reduced to about 0.02 oz. wt.

It is not possible to give a precise estimate of the quantity of air required by any given pneumatic gauge. The consumption will depend, of course, on the mean escapement area at the measuring head and on the pressure used. The following table, which gives the results of some measurements made at NPL, may serve as a guide for calculation. In each case the flow, expressed in cubic feet of free air per minute, is given for a simple jet impinging directly on a surface.

Diameter of Jet (D)	Distance of Jet from Surface (L)	Pressure at the Jet (p)	Flow
in.	in.	lb./in.^{2}	ft.^{3}/min.
0.05	0.005	10	0.4
0.03	0.003	10	0.15
0.02	0.002	10	0.09

2. *Measurement of the Varying Pressure p*

For indicating the variation of the pressure p between the control orifice O_c and the measuring orifice O_m, a choice of means is available.* The water manometer offers a simple method for low pressure work. For higher pressures, a pressure gauge, in which the sensing element is either a Bourdon tube or a flexible bellows, may be used. The pressure gauge should have a full-scale reading corresponding to P. Since the variation in p will be confined to the range 0.6 to 0.8 P for 1 % linearity, or to 0.5 to 0.9 P for an inferior linearity, only part of the scale of the pressure gauge will be used for measurement, a point to be remembered when deciding the size of dial required. When a flexible bellows is used as the sensing element, it is usually advantageous to use the bellows differentially, applying the constant pressure P on one side of the bellows and the variable pressure p on the other; the bellows now responds to $P - p$ and the arrangement has the advantage of giving partial compensation for undesired changes in P.

Another arrangement is one based on the well-known Wheatstone bridge principle. This is illustrated diagrammatically in Fig. 5 which shows a scheme for measuring the displacement of a surface S_1. The constant pressure P is supplied to the measuring circuit, comprising the control orifice C_1 and the jet J_1, and at the same time to a similar circuit C_2, J_2, the second jet blowing on a fixed surface S_2. The bellows measures the difference $p_1 - p_2$, its movement being magnified by suitable means. This arrangement also compensates, though not completely, for changes in P. If, for example, the maximum value of $p_1 - p_2$ is $\pm$ 0.1 P, a 2 % change in P produces only a $\pm$ 0.2 % change in $p_1 - p_2$. A "Dial Air" gauge has been developed especially for pneumatic gauging, using this principle, the movement of the bellows being magnified mechanically and displayed by pointer and scale. The second jet and surface are replaced by a needle-valve which, being adjustable, also provides for zero adjustment.

* Whichever means are adopted, the pressure measuring device would, of course, be fitted with a scale appropriately graduated in units of length.

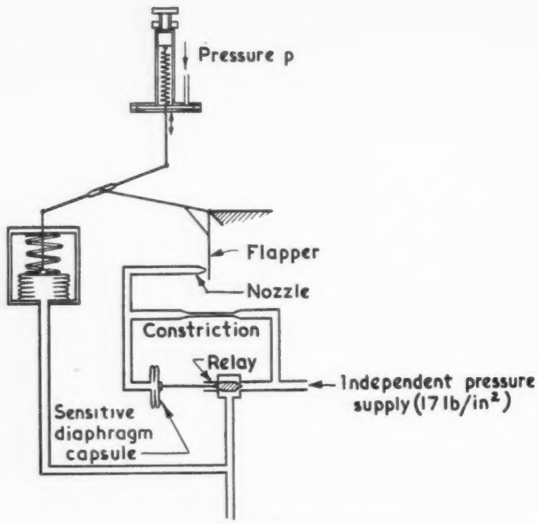


Fig. 6. Scheme of amplification when measuring textiles.

When it is required to record, rather than to indicate, the variation of the pressure p, use may be made of pressure recorders with Bourdon tube or bellows-driven elements to which the pressure is fed directly. A method of recording developed by the Author some years ago for measuring textiles (which necessitated working at pressures not exceeding 1 lb./in.^{2}) is shown schematically in Fig. 6. The variable pressure p was fed to the back of a spring-loaded diaphragm made of two thin aluminium disks, with a closing annulus of thin polyethylene sheet. The diaphragm displacement was linear with pressure to within 1 % and the rate of the spring was such as to produce a displacement of $\frac{1}{8}$ inch for a change of pressure of 2 inches of water. The diaphragm was coupled mechanically to a Pneumatic Motion Transmitter, which can provide a change of output pressure of about 12 lb./in.^{2} (i.e. from 2 to 14 lb./in.^{2}) for an input displacement of $\frac{1}{8}$ inch and is linear within 1 %. The principle of operation of the transmitter, which is completely free from drift, is interesting and an account of it has been given in an earlier Paper.(2)

The use of a pressure transducer and pneumatic amplifier has two advantages: it allows for depression of zero so that full scale deflection is made to correspond to the full linear change in p, and it provides signals at power level which may be used for automatic control. Other types of pneumatic amplifier are available and the pressure transducer may, of course, be a spring-loaded bellows.

3. *Design of Measuring Heads*

The extreme flexibility of the pneumatic gauging technique is very much the result of the wide latitude permitted in the design of the measuring head. The designer's slogan might well be: "To each job its measuring head." It would be tedious and unrewarding to attempt to describe the numerous designs which find a place in industry. The discussion will therefore be confined to a statement of the general principles to be followed when considering the most suitable form of measuring head for any particular problem, with an indication of the types which have been found successful.

Measuring heads in use may be divided broadly into two classes:—

Class I: Those in which a change in the size of the dimension being measured directly affects the air escapement.

Class II: Those in which a change in the size of the dimension being measured affects the air escapement indirectly.

The jet blowing directly on a surface whose displacement is to be measured (Fig. 4) is an example of a measuring head of the first class. No contact is made with the work under measurement. This, however, is not always true for measuring heads of this class; thus, the head shown in Fig. 7 (a) for measuring material in thread or wire form belongs to Class I, but in this case there is or may be contact. In the Class II measuring heads, a stylus makes mechanical contact with the work-piece, the air escapement being altered as a result of the movement of the stylus. An example is shown diagrammatically in Fig. 7 (b). Both classes of measuring head have their advantages and the choice between them usually turns on the kind of measurement required.

Class I measuring heads lend themselves readily to the design of pneumatic gauges for measuring over a short range at medium or high sensitivity; they are not so useful for measuring over long ranges. Thus, the jet of Fig. 4 set at 0.002 in. from the surface will very conveniently measure displacements of this surface within the range ± 0.0005 in. with a linearity within 1 %; set at 0.006 in. it will similarly cover the range ± 0.0015 in. It is not, however, convenient to extend the range very much further, especially if several jets are being used simultaneously because the air flow becomes large (cf. p. 117).

Class II measuring heads, on the other hand, are particularly suitable for measurements over longer ranges. In the type illustrated in Fig. 7 (b), the stylus arm can be so proportioned that the displacement of the plate in relation to the jet is less than the corresponding movement of the stylus. In other words, the jet and plate, which comprise a Class I measuring head, are used at a convenient range and sensitivity but the overall magnification is reduced, and the permissible range of measurement increased, in proportion to the reduction ratio of the stylus arm. Another example of the Class II measuring heads is shown in Fig. 7 (c). Here, the axial movement of the stylus varies the area of the escapement annulus M and the relative rates of change of these two quantities,

which depends on the rate of " taper " of the inner member, can be selected to provide linear response over the range of measurement required. With this type of measuring head, usually known as a poppet valve, it is not difficult to extend the measuring range to 0.025 in. or even more.

Before proceeding to consider the other forms of measuring head illustrated in Figs. 7 and 8, it will be well to recall the requirement mentioned earlier (p. 112), namely, proportionality between change in the dimension under measurement and the corresponding change in the escapement area M. For the simple jet (Fig. 4) proportionality is secured as long as the effective escapement area is represented by $k \pi D L$. This condition can hold only within certain limits—it is obviously not the case if the jet is, say 3 inches away from the surface. The limiting value for L will depend on the diameter of the jet and experience at NPL has suggested that L_a should not be greater than $1/10D$. (It is this qualifying relationship between D and L_a which renders it undesirable to use the simple jet for measuring dimensional changes over a large range. Thus, a linear measuring range of 0.005 in. would require L_a to be 0.01 in. and D not less than 0.1 in., and this would entail a large air consumption i.e. a few cubic feet per minute). In the case of the poppet valve, linear relationship between axial movement of the stylus and change in the escapement annular area M calls for the moving member to have a parabolic section. The linear range of measurement of the stylus will depend on the latus rectum of the parabola.

To resume consideration of the types of measuring heads available, Fig. 7 (d) shows a design for measuring the thickness of a work-piece bounded by flat, parallel surfaces; it may also be used for determining the diameter of a cylindrical work-piece. The two jets are connected in parallel and the total escapement area at the measuring head (i.e. M) is now the sum of the escapement areas of the individual jets. It is tempting to think that the disposition of the work-piece within the caliper is immaterial, that a movement of one face of the work-piece towards one jet will be compensated by the equal movement of the opposite face from the other jet, but this is not true. There is, of course, a partial compensation, but for very accurate measurement it is necessary to retain symmetrical disposition of the work-piece between the jets. When measuring thickness, there are two ways of overcoming this difficulty. Each jet can be made with a guard ring (see Fig. 8 (a)) so as to limit the excursion of the work-piece from the symmetrical position, or the work-piece can be laid on a flat table with a central hole, the two jets being then arranged as in Fig. 8 (b). Either method of course, limits the gap into which the work-piece must be placed, the degree of limitation depending on the accuracy of measurement required. Mention may be made of a scheme adopted at the NPL when using a caliper with two jets to measure to 1 micro-inch the variation of thickness of a very accurately made cube of metal. It was necessary to traverse the caliper in steps across the cube and after each movement to set it symmetrically in relation to the cube faces. By

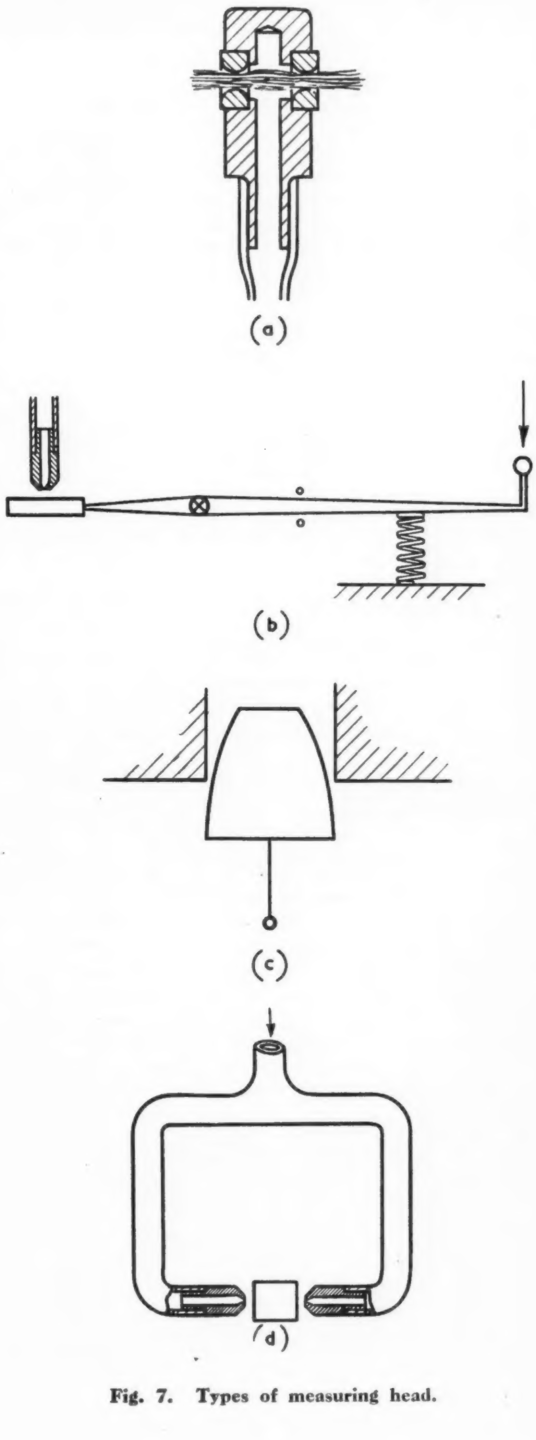


Fig. 7. Types of measuring head.

a simple modification of the pneumatic circuit, one of the jets could first be used alone to measure the position of the cube within the caliper, and then both jets used together to measure the thickness.[8]

It will be clear that for measuring the separation of two parallel surfaces, or the internal diameter of a bore, two jets may be used in parallel in the form of an internal caliper (Fig. 8 (c)). The point made in the previous paragraph with regard to the symmetrical disposition of the work-piece and caliper will apply. In a gauge introduced many years ago by a well-known company for the measurement of bores,[4] adequate symmetry is achieved by inserting the caliper within a plug whose diameter is suitably related to the bore to be measured.

Whichever type of measuring head is used, it must be remembered that it is the total impedance to the flow to atmosphere of the air which has passed through the control orifice that determines the value of p. It is, therefore, important, for otherwise sensitivity will be reduced, that any obstruction to the air flow prior to the final escapement path (e.g. the cylindrical area in the case of the simple jet) should be relatively small. The piping connecting the measuring head to the control orifice should be sufficient diameter to meet this requirement and it should, of course, be free of leaks. Similarly, constriction within the jet itself must be avoided.

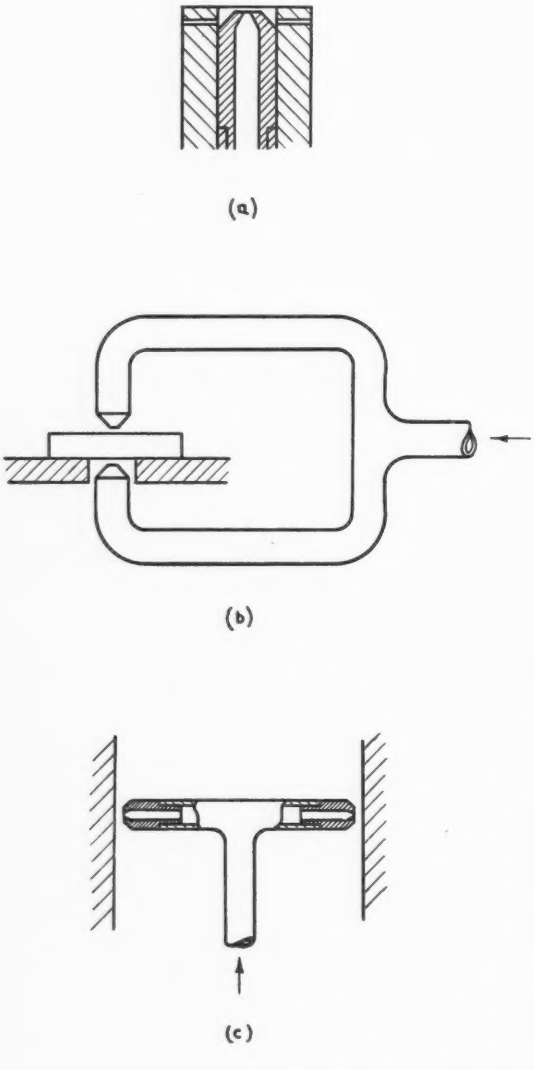


Fig. 8. Types of measuring head.

4. *Control Orifice*

The equations defining linear range, pneumatic sensitivity and overall magnification which were derived in the earlier part of this Paper do not explicitly include a term representing the influence of the control orifice. This was deliberate because it is expedient, and in practice convenient, to regard the escapement area of the control orifice as the variable to be adjusted last. The simplest form of control orifice is a small hole in a brass plate and experience indicates that this form is usually adequate. It is not easy, however, to make an orifice to a pre-selected value because of the influence of the periphery; indeed it is usual to find that reversing the plate alters the effective escapement. When the scale of the pressure measuring device is to be graduated specially, by pointing and dividing, so that the exact value of the sensitivity is unimportant, this difficulty is of no moment. But if the scale is already prepared, or if several parallel circuits are to be used with a common pressure measuring device, so that a pre-arranged sensitivity must be achieved, the following scheme may be used. The pneumatic circuit is first set up with a needle-valve as control orifice and this valve is adjusted to give the required sensitivity. The plate orifice is then connected in parallel with the needle-valve, two stop-cocks being introduced so that orifice or needle-valve may be introduced at will into the circuit. The orifice is then enlarged, by trial and error, using a suitably tapered reamer, until it is exactly equivalent to the needle-valve.

The diameter of the orifice will, of course, depend on the average escapement at the measuring head, but it will usually fall within the limits 0.015 to 0.050 in. A plate diameter of $\frac{1}{4}$ in. and a thickness of about 0.025 in. are convenient, and it is desirable that the periphery of the hole should not be ragged. By soldering the plate to the end of a short tube of equal diameter, the control orifice may be readily connected to the pneumatic circuit by means of flexible tubing.

For experimental work in the laboratory, the needle-valve is a particularly convenient form of control orifice and is strongly recommended. It is readily adjusted to meet individual requirements and will cover the full range of escapement likely to be needed. It can be replaced, in the manner described

above, by the simpler (and cheaper) plate orifice when the experimental circuit is to be built into a permanent apparatus.

Calibration and Performance

The pneumatic gauge is, of course, a comparator and it cannot provide absolute measure without reference to standards. Thus, the vertical pneumatic comparator for measuring flat work-pieces, shown diagrammatically in Fig. 9, will enable the absolute size of the work-pieces to be determined only if (1) a known standard, e.g. a slip gauge of the same nominal size as the work-piece, is available and (2) the scale of the pressure gauge has been correctly graduated in units of length to allow the difference in size of the work-piece and the standard to be read. The second requirement is, of course, met in the initial calibration of the instrument by using two standards, the difference between which is equivalent to the full measuring range of the gauge. If the scale is uniform and the instrument is always used within its linear range, the calibration so obtained will be sufficient and will remain unchanged provided the overall magnification remains unaltered. Any doubts regarding linearity can be resolved by taking additional readings on standards of intermediate sizes during the calibration; during subsequent use, the constancy of the magnification can be checked periodically with the aid of two standards giving readings near the lower and upper ends of the range. It must be remembered that the sensitivity of the comparator depends on the constant pressure P at which it is used and it is important, therefore, to check that this pressure is correct.

The comparator in Fig. 9 may equally well be used for measuring cylindrical work-pieces, provided that the standards employed are also a cylindrical form. This point, that the standard should be of the same form as the work-piece, is always an important one in accurate measurement; it is especially important when using a pneumatic gauge fitted with a Class I measuring head. It is also necessary that the surface roughness of the standard should not be appreciably different from that of the work-piece, because the readings of a pneumatic gauge are influenced by the quality of finish of the surface on which the air impinges.

The effect of surface roughness on the reading of a pneumatic gauge is worthy of further consideration. Fig. 10 shows a " rough " surface in which, for convenience, the " texture " is assumed to be of a simple, regular form. Alongside are shown two perfectly smooth surfaces, one coinciding with the plane through the crests and the other with the plane through the roots of the rough surface. The escapement area for the centre jet will clearly have a value intermediate between those of the other two jets. The pneumatic gauge thus gives for the difference between the work-piece and the smooth standard a result to which the roughness of the surface of the work-piece has contributed; and this result would not agree with the value which would be obtained if the comparison were made with a mechanical comparator making contact with the surface by means of a flat anvil of, say, $\frac{1}{8}$ in. diameter. Since it is the

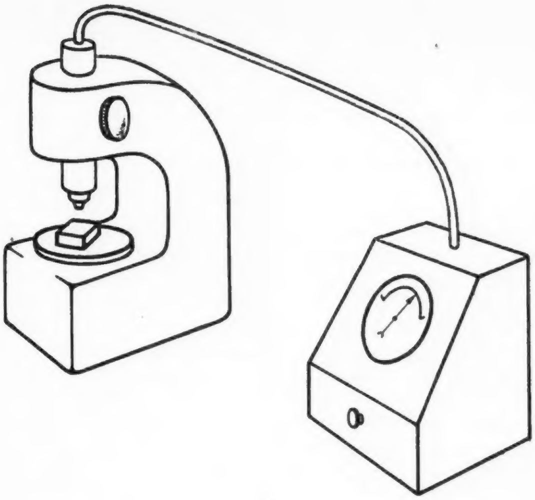


Fig. 9. Vertical pneumatic comparator.

tactual measurement which gives the value usually needed for practical purposes, e.g. for controlling the fit of mating parts, it is best to eliminate the difference which roughness of the surface introduces when using a Class I measuring head, by providing standards having a similar quality of finish to that of the work-pieces. The influence of surface roughness on the reading of an air gauge implies the possibility of using the pneumatic technique for measuring surface finish and pneumatic instruments for this purpose have been developed.[14,15]

In certain applications of pneumatic gauging, e.g. to the measurement of the weight per unit length of a textile material by means of a measuring head of the form shown in Fig. 7 (a), it is not possible to calibrate the apparatus by direct reference to known standards of length. In such cases, indirect means of calibration must be employed, samples of the work being measured pneumatically and also by some other method which provides absolute values. Thus, for the textile material, the weight per unit length of several samples, selected so as to exhibit the full range of variation, may be determined by weighing

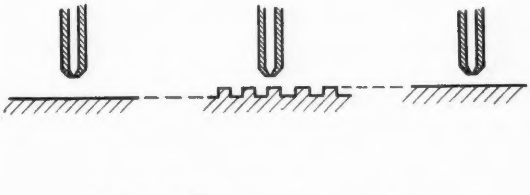


Fig. 10. Effect of surface roughness.

measured lengths, the values so obtained being then graphed against the corresponding pneumatic measurements to provide a conversion chart.[2]

When using a complex pneumatic gauging apparatus over long periods of time, it may be useful to have available a simple means of checking the overall working of the apparatus. An auxiliary pneumatic circuit comprising two orifices in series will serve the purpose. The constant pressure P is applied to this circuit and the sizes of the orifices are so chosen that the intermediate pressure p corresponds approximately to the mid-point of the measuring range of the apparatus. A constant signal of known value is thus provided and, with suitable switching arrangements, this may be injected periodically into the pressure measuring device. If the correct reading is shown, the equipment is in good general order, though of course, it does not necessarily follow that the various measuring circuits are operating still at their initial sensitivities. Care must be taken in designing the switching arrangements to ensure that no air leakages are introduced or likely to develop since they would, of course, introduce serious errors. Experience at the Laboratory has shown that the well-known Schrader valve may be used as a switch for low pressure systems, say P not greater than 5 lb./in.^{2}

As regards performance, perhaps the most striking quality of pneumatic measuring instruments is their remarkably high degree of repeatability even when working at magnifications of the order of 30,000. The instruments are robust and, in contrast to electronic measuring instruments of similar sensitivity, quite free from drift. They are usually unaffected by normal changes in room temperature, pressure or humidity. The speed of response is amply fast for the types of measurement required in workshops and standards rooms, and for continuous gauging in the factory, when the essential purpose is to obtain information as to trends in the production.

With a suitable measuring device and a correctly designed measuring head, linearity within 1% is assured over a range x defined by $0.6 < \frac{p}{P} < 0.8$; measurements over the interval x may be made, therefore, to an accuracy of $\pm 0.01\, x$. As mentioned earlier, this range may be doubled if some loss of linearity (and accuracy) at the extremes is acceptable. Further extension of the range leads to marked non-linearity due to a rapid fall-off in the pneumatic sensitivity. This attribute can, however, be turned to advantage in some applications. Thus when a pneumatic gauge is used for sizing a work-piece whilst it is being machined, extension of the scale well beyond the linear range enables the operator to watch the approach to size at a lower magnification.

A question frequently asked regarding the performance of a pneumatic gauge which is measuring continuously the thickness, or some other dimension, of a moving material, is whether the speed of the material through the measuring head influences the gauge reading. No evidence of any such influence has been found in experimental work at NPL for moderate speeds. Thus, for example, when determining the weight per unit length of cotton sliver[2] with a measuring head of the type shown in Fig. 7 (a) the result was not affected by varying the speed from 1 to 100 ft./s. At the Mechanical Engineering Research Laboratory an investigation was carried out in which a circular plate of diameter 10 in. was mounted concentrically in the chuck of a lathe and a jet set up to blow in a radial direction on the periphery of the plate. The results showed no significant change in reading when the plate was rotated at speeds up to 2000 rev/min.[13]

Applications

Pneumatic gauging found its first main application in the measurement of bores, particularly in the automobile industry, and it is probably true that this use of the technique is still predominant. In the last decade or so, however, manufacturers of air-gauges have applied the technique successfully to an ever increasing number of problems of linear measurement, with the result that industry in this country is now making much more use of pneumatic gauging. Even so, this method of measurement has not yet become so extensively adopted here as it has in America.

The catalogues of the manufacturers concerned show the wide range of air-gauges now made. But the individual problem, calling for the design of a special gauging fixture, probably still makes the greatest demand on the manufacturing capacity available, and one of the chief difficulties lies in so rationalising the production as to provide for the maximum number of applications with the minimum number of standard units. It is not proposed to enumerate here the various types of air-gauges now commercially available, but perhaps special mention might be made of the so-called multi-gauging units which allow a number of dimensions to be checked simultaneously. The pneumatic technique, by virtue of its flexibility, lends itself readily to the design of such measuring instruments, and the wide range of sensitivity readily available permits a common tolerance zone to be used in the display unit, though the various dimensions being checked may have widely different tolerances.

Some reference has already been made to work on pneumatic gauging undertaken at the National Physical Laboratory. Most of the instruments developed have been described in published Papers, references to which will be found at the end of this Paper.[9, 10, 11] Recently, apparatus has been constructed for recording continuously the thickness of material (e.g. cellulose acetate, polyethylene) in thin sheet form during production.[12] The measurements may be made at as many stations across the sheet as is desired, a simple selector switch enabling transfer from one station to the next to be made easily and quickly. The thickness is measured absolutely with an accuracy within $\pm 0.000\,02$ in., the overall magnification, measured at the recorder, being approximately 7000. Alternatively, instead of recording, the thicknesses at the various stations may be displayed continuously on water manometers, any variation in thickness from station to station being then rendered

(*Concluded on page* 140)

PRACTICAL MARGINAL COSTING

by W. E. HARRISON, F.C.W.A., A.M.I.I.A.

Presented to the London Section of the Institution, 19th January, 1956.

Mr. Harrison has been in practice as a Cost Consultant (or Consulting Cost Accountant) for over 20 years, and has installed and operated systems of Marginal Costing for about the same period.

He is a Fellow of the Institute of Cost and Works Accountants, of which association he is a Past President and a former Chairman of their Research Committee.

This Paper is based on a Paper presented to a Regional Conference of the Institute of Cost and Works Accountants at Sheffield.

IN making my opening remarks, I should like to say that I regard marginal costing as an extremely practical subject. It is not just something the theorists play with and throw on one side. If it were, I should not be interested in it. I hope to give you some of its uses in which you, as production engineers, will be most interested. But before doing so, I must deal with the theory.

I should like first of all to define the subject. Marginal cost may be defined as the amount, at any given volume of production or output, by which aggregate costs are changed if the volume of production or output is increased by one unit. In more simple terms, if, starting from the position we are in now, we produce one more of a certain product, the added expenditure entailed is the marginal cost of that product.

I do insist that we start from the position we are in now. I find that many accountants and cost accountants want to start from somewhere else. I refuse to start from any position other than the one we are in at the present time.

The main feature of a marginal costing system is the separation of the variable costs from the fixed costs of a business, and the control of each type by varying methods, so as to give maximum efficiency and to reveal the effect upon profit of changes in output.

Here I would say that I do not intend to ignore fixed expenses. There was a lot of correspondence some years ago in one of the accounting journals on whether fixed overheads should be ignored in costing. The last thing that the real 'marginal coster' does is to ignore them.

I want to jump now, in the sequence of the Paper, to Appendix A. You will find at the top Schedule C, showing Product "A", Product "B" and Total. I want you to imagine the Product "A" column as showing the present accounts of a small retail shop. Mrs. Smith sells chocolates and during the year her sales are £3,000. The costs of the chocolates from the supplier are £2,000. The fixed charges on her retail shop are £750. She shows a net profit of £250. I want you to accept that this is a fact at the moment.

Along comes an enthusiastic salesman for cakes. He says to Mrs. Smith; "If you sell cakes in your shop, you won't compete with your chocolates. You won't increase your fixed overheads, and there is a chance in a shop such as this that you will sell £1,000 worth of cakes." She says, "Yes, what do these cakes cost me?" The salesman replies, "£800." If that salesman's promises can be accepted, the marginal coster would draw up a budget—the emphasis is on the word 'budget'—for Mrs. Smith as shown in Schedule C. He would show the position as it is now in the Product "A" column. He would show the additional costs due to the introduction of cakes in the Product "B" column. The net result, bearing in mind that Mrs. Smith in the retail shop is not likely to increase her fixed overheads and the cakes will

not compete with the chocolates, will be shown in the Total column. If the salesman's promises are maintained, then Mrs. Smith's net profit will jump from £250 to £450.

"But," says the orthodox cost accountant—and I use the term 'orthodox' in no slighting manner—I want to differentiate between the orthodox and the marginal cost accountant—"you ought not to do it like that. You ought to spread your fixed charges in proportion to sales." The orthodox cost accountant would do it as is shown in Schedule D. The totals of Schedules D and C are exactly the same. The sales and the cost of the goods sold are exactly the same. But in Schedule D the fixed charges are divided in proportion to sales—£562 under Product "A", chocolates, and £188 under Product "B", cakes. The orthodox cost accountant would show a profit of £438 on chocolates and £12 on cakes.

Suppose Mrs. Smith, selling cakes, could only sell £500 worth which she buys at £400. The orthodox split of overheads would be as shown in Schedule E—*pro rata* sales £643 for Product "A" and £107 for Product "B". Whilst the total column is accepted by both orthodox and marginal coster, the split by the orthodox cost accountant is as shown in Schedule E, which gives a profit of £357 to Product "A", chocolates, and a loss of £7 to Product "B", cakes.

If the orthodox cost accountant had stepped in at that stage and had said to Mrs. Smith, "You will make a loss of £7 on your cakes," it is highly probable that Mrs. Smith would not have started to sell cakes. And if she had not started to sell cakes, the result of her year's trading would have been as shown in the Product "A" column of Schedule C, a profit of £250 instead of, as shown in the total column of Schedule E, a profit of £350. In other words, by taking on a job which, according to orthodox costing, showed a loss of £7, Mrs. Smith adds £100 to net profit.

Let us go a stage further. Let us suppose that at the moment—now—Mrs. Smith is doing exactly as is shown in the total column of Schedule E. She is selling goods worth £3,500 which cost £2,400. Her fixed charges are £750, and she has a profit of £350. Let us suppose that along comes the orthodox cost accountant and tells her she is making a profit of £350 on chocolates and a loss of £7 on cakes. It is highly probable that she will say that if she is making a loss on her cakes, she will stop selling them. If she stops selling them, her profit will drop from £350 to £250.

If there are any orthodox cost accountants here, that is exactly what they are doing to their management day by day. They are presenting hundreds of costs, some of which show profits and some of which show losses. There may be a loss of £7, such as is shown in Schedule E under Product "B". If management looks at the list and says, "We are losing £7 on this. We will cut it out", in the circumstances as shown their advice or implied advice, unless they give a lot of explanations to management, may result in action which will reduce profit by £100.

A Common Weakness

I think that is important. The weakness of the commonly accepted or orthodox technique of costing is that information is not presented in the best possible way unless detailed explanations are given when it is necessary to make comparisons between one line of action and an alternative. I suggest that management is always concerned with a decision regarding certain lines of action. If we bring it down to its simplest expression, management always has to decide either to do something or not to do it. It is as simple as that. Management may decide to do "A" or "B" but there is always the alternative in the middle in each case — to do nothing. If you wish to bring your thinking down to elementary first principles, every decision is to do something or to do nothing.

I suggest, as a marginal coster, that the inclusion of fixed charges in the overheads makes it difficult firstly to compare the effect of different courses of action; secondly, to measure the true efficiency of sections or departments; and thirdly, to fix selling prices so as to give the best results for the business as a whole.

The Initial Decision

My argument is that when a business is commenced, its management decides that there is a demand for a certain commodity which is not satisfied and considers that, if a factory is established to produce that commodity, it can produce adequate quantities of the approved quality at the right price, can pay wages which will at least maintain the standard of living of the type of worker required, and will leave a profit for enterprise. Having made this decision, management proceeds to build or rent a factory, to install plant and machinery, to make jigs and tools, to appoint a secretary and other staff, to equip the offices, and to advertise the products. All these things are done as a matter of policy, and the so-called "fixed costs" which appear in the first year's accounts could well be designated "policy costs." This term could be used for all those items which should be excluded from marginal costs.

The capital expenditure, and the costs automatically acquired by the business because of this expenditure (such as depreciation), together with such charges as have been mentioned, were incurred as a deliberate policy, to make profits over a long period, and any system of cost accountancy should reflect this. On the other hand, "variable" or "out-of-pocket costs" are incurred, as production is carried out, and should vary practically in proportion to production.

As a matter of business policy, therefore, management has two jobs:

(a) Over a long period to make sales *minus* total costs (i.e. net profit) as high as possible.

(b) Over a short period to make sales *minus* marginal costs (which may be termed "contribution") as high as possible.

Long-period policy has been considered before the business was commenced, and unless management was convinced that, over a long period, net profit would result, it is reasonable to assume that the business would not have been started. The business having been started, the short-term policy must be considered, and management should attempt to make the contribution as high as possible without, of course, forgetting long-term policy.

As an aside, I have often—I repeat often—come across managements who have first-class ideas for long-term policy but completely overlooked how they were going to pay the wages at the end of next month. It is not a bit of good having long-term policy perfectly tied up if you do not get over the intervening period.

Where cost accountants are required to advise management upon the initiation of business ventures, they must consider both long- and short-period policy, but maximum consideration will of course be given to the long period : in the businesses with which we are connected the decision to produce has already been made, and therefore maximum consideration is given to short-period policy. In both sets of circumstances the separation of out-of-pocket costs from policy costs is of paramount importance.

Under marginal costing systems we accept the position " as is "; that is, we recognise the fact that the business is in a certain position at the present time, and we show clearly what will be the effect of any action taken. This is not shown by any other system of costing, unless detailed and lengthy explanations support the costs.

Practical Applications

The practical application of a system of marginal costing is no more difficult than is the work of any other system of costing, and it can be used with job, process or operating costs. The method of dealing with materials and labour is not affected. Overheads alone are the problem, and even here there is little variation—merely an expansion of normal technique. The normal costing methods call for :

(a) classification of all overheads under appropriate heads;

(b) collection of overheads actually incurred period by period;

(c) apportionment of overheads to production, selling, distribution, and administration;

(d) subsequent apportionment to departments, services, and producing units in the proportions in which it has been incurred;

(e) allocation to the products passing through the production departments on the appropriate bases, e.g., as a percentage on labour, labour hour rate, or machine hour rate.

With marginal costing, changes start immediately. The classification in use may be sufficiently detailed, but if not it must be extended to separate the fixed costs from the variable costs. It is here that the bulk of trouble and disagreement will arise. If we think of policy costs and out-of-pocket costs and squarely face the position of our business as it is at the moment, we shall ultimately get this division. If management policy should be changed in the future we must face up to the position as it is. In other words, our costs must always represent the facts as they are. For example, if management decides to scrap a battery of machines and do a job by hand (or *vice versa*), our costs must show this change and must separate policy costs from out-of-pocket costs.

What are fixed (or policy) costs will obviously vary to some extent from business to business, according to the policy adopted by management; but speaking generally the following are policy costs : directors' fees, auditors' fees, legal and professional charges, salaries, rent, rates, fire insurances, depreciation of all types (true depreciation), practically all office and administration charges, office equipment, travelling and hotel expenses, advertising of all descriptions.

Out-of-pocket expenses include : most—or perhaps I ought to say much—indirect labour, consumable stores and tools, national insurance, employer's liability insurance, most power services, freight and carriage, packing materials, discounts and allowances, agents' commissions.

The collection of overheads actually incurred, period by period, will not differ under any system, but in the subsequent apportionments and allocations to products, the out-of-pocket or marginal overheads only are considered, in the first case.

The bases of apportionments and allocations are the same as under a normal system of costing, but, since fixed or policy overheads are excluded, the apportionment to departments, services, producing units or cost centres is likely to be more simple, and the allocation to products passing through the production departments, on the appropriate bases, will be more simple and more accurate. Under the usual methods of costing, normal annual overheads are spread over normal annual production, and periodically (usually each year but often at more frequent intervals) the cost accountant is required to compute rates of overhead recovery based on these " normal " figures. Now there is no such thing as a static normal; conditions are constantly changing; and the opinions of general manager, works manager, departmental foreman, and cost accountant, or even of two cost accountants in the same business, are likely to differ widely in their assessment of normal. The result of this is that when we have applied our so-called normal overheads over normal production, and have obtained a normal rate of overhead recovery, which has been applied to subsequent production, we always end our costing year with an over-recovery or under-recovery of overheads in all departments. This must be so, since any change in anticipated overheads or production will cause an error.

With marginal costing these errors are far less likely to arise, since we intend to recover over our production only those items which are incurred in the use of the production facilities and therefore vary more or less in proportion to production. Anyone

who, even with ordinary methods of overhead recovery, has investigated the reasons for variations in the recovery of overheads, cannot fail to have observed that marginal or out-of-pocket overheads really do keep step with production; they will agree that the computation of marginal overhead rates will be more simple and more accurate than the computation of total normal overheads including all the chargeable fixed or policy costs.

In the same way as marginal production overheads are considered, marginal costs of selling and distribution must be considered. In these sections one cannot fail to recognise the ease of allocation or the accuracy of the results, once fixed overheads are eliminated from the computation. Having carried out this procedure, it is a simple matter to compile the marginal cost of any product with far more accuracy than the total cost can be compiled.

Budgetary Control

It is not suggested that fixed costs should be ignored; the cost accountant must certainly deal with these costs from the angle of control. Further, until both management and cost accountant have grasped all the significant features of the technique, it is probable that they will wish to see how the normal orthodox cost compares with marginal cost, for price-fixing purposes. From the control point of view, a system of budgetary control is required, the budget being of a flexible type to take into account changes in the volume of production. This flexible budget is not inconsistent with the idea of fixed overheads if they are regarded as policy costs: thus, up to a certain volume of production a business can manage with its present equipment; at that stage it must—as a matter of policy—purchase more plant and machinery, which will increase its policy costs. Period by period the actual fixed overheads must be compared with the budget—and because the budget has been compiled as a matter of policy, management is easily able to compare the actual policy, as it is being carried out, with the boardroom or "paper" policy. Control of the business as a whole is therefore exercised through standards for marginal costs, and by means of budgetary control for fixed or policy overheads; and the efficiency of all departments can be most readily seen and illustrated without extraneous matter by these methods.

It is very simple to compile a normal cost from a marginal costing system.

You merely take the fixed overheads, so far omitted from the cost computations, and spread them over production, selling and distribution departments on the recognised bases, afterwards distributing these departmentalised charges to production and sales by means of the usual methods—man- or machine-hour rates for production overheads, or percentages on selling price for selling costs.

I put that in because I feel that in the initial stages, for the sake both of the cost accountant and of management, it is a wise thing to do. The change to marginal costing is so revolutionary that they might want to see both sides of the subject, and that is the way to do it. It is a very simple way, too.

Now I come to Appendix B. Here a job can be done on a power press at a labour cost of 4d. per gross, or on a hand press at 6d. per gross. Normal rates of overhead recovery amount to 150 per cent. on power press labour and 50 per cent. on hand press labour. Ample material, presses and jigs are available. Materials cost 4d. per gross. Shall the job be done on hand press or power press? In case you think the figures are out-of-date, I would say that this was done about twenty years ago. It was actually taken from facts and rounded off. You will see that on the hand press the production is three gross per hour, while on the power press it is six gross per hour. The material cost is 4d. per gross, and the piece-work price is 6d. per gross on the hand press and 4d. per gross on the power press. Thus, the hand press operator can earn 1/6d. per hour and the power press operator can earn 2/- per hour. You see how out-of-date these figures are! Full overheads are 3d. per gross on the hand press and 6d. per gross on the power press. If you care to ignore the 150 per cent. and the 50 per cent., you can; because the fact that in that particular business they did recover overheads as a percentage of labour, instead of a rate per labour hour or per machine hour, does not alter the case at all. Total cost is 1/1d. per gross hand press, 1/2d. per gross power press, as shown by orthodox costing.

Let us assume the selling price was 1/3d. We have an apparent net profit of 2d. per gross on the hand press and 1d. on the power press, as shown by orthodox costing. Thus, orthodox costing would imply to management that the hand press was twice as profitable as the power press.

But the marginal coster says, "You must only consider marginal overheads. Your fixed overheads are there, whether you like that or not." You have your hand press and your power press. Plenty of facilities are available. Consider the following figures:

	Hand press	*Power press*
Marginal overheads	2d. per gross	4d. per gross
Marginal cost ...	1/- per gross	1/- per gross

i.e. 4d. material 6d. labour 2d. overheads	hand press
4d. material 4d. labour 4d. overheads	power press

The price is still 1/3d., so there is a contribution of 3d. per gross in each case.

The marginal coster with the 'L' on his back says it does not matter whether you do it in one way or the other; but it does matter. On the hand press, you get a contribution of 3d. per gross three times every hour. That is a contribution of 9d. per labour hour. On the power press you get a contribution of 3d. six times an hour, or 1/6d. per labour hour.

The marginal coster shows management that it is twice as profitable to do the job on the power press as on the hand press, whereas the orthodox cost accountant would tell the other tale.

In my opinion—and I ought to preface everything I say in this lecture by the words 'in my opinion'—the lesson which is learnt from that illustration is one of the most important lessons of marginal costing. As production engineers, you will realise how important it is.

I have used two simple machines, in fact so simple you can hardly call them machines. But in your businesses you have machines which cost far more than these to run. You have them in your works now. They may or may not run to capacity. It is absolutely essential that you should know which machine is likely to give the greatest contribution to your business if a particular job is put on it. I suggest that the manner in which contribution per "key factor" of production is presented to management by marginal costing methods is certainly one of the most important reasons for its use.

The "key factor" in this particular case—and I said ample facilities, materials and so on were available—was labour. Labour today is very often the key factor. It may be labour, or it may be a certain class, type or grade of labour. It may be materials, or a particular material. It may be an item of plant, or overhead facilities. The marginal costing technique alone shows clearly how the maximum net profit is achieved by obtaining the maximum contribution per unit of cost which is in short supply, i.e., per key factor of production.

In a Paper I presented recently, I made this specific recommendation which will, I think, be of interest to you:

> "It is therefore to be recommended that machine-hour rates computed on a marginal cost basis should be in the possession of the production planning staff in order that jobs be put on the best available machine with the lowest marginal cost, and consequently the best contribution per key factor of production."*

To Make or To Buy?

We now come to a very simple application of marginal costing—to make or to buy? When considering whether a product should be made in the factory or bought from an outside supplier, it is of little value to compare only the full orthodox cost of the product with the outside supplier's price. However, if the 'out-of-pocket' costs to the business be considered, the comparison is valuable.

If facilities for production are available within the factory and the marginal cost of production is less than the supplier's price, then it is more economic to make than to buy. If the outside supplier's price should be less than the marginal cost of production, then it is better to buy than to make.

In the consideration of the problem here the full orthodox cost is of value. Since the outside supplier will most probably have quoted a price which includes his full overheads and a profit, it is logical to suggest that the full cost of producing the article within the factory should be less than the supplier's price. If this is not so, assuming the product to be within the normal range of factory production, there is an indication of production inefficiency within the factory. In such a case, it would be wise to investigate the methods and cost of production within the factory.

Here is a case where both marginal cost and total cost are of value. It is contended, however, that the ascertainment of marginal cost and the indication of 'contribution' are of the greater importance.

Control of Cost

I should like to come now to control of cost. Here again you will be interested in your jobs as production engineers.

It is logical to suggest that management, at any level, is interested in and should be held responsible for those expenses which they can influence by their own action, or which are influenced by the actions of the staff under their immediate control. 'Functional' budgets recognise this.

Under a system of marginal costs, there is presented to the shop foreman a summary of the figures which he can influence by his action—the marginal costs of his department. Where standard marginal costs are in use, the actuals are compared with the standards, and the reasons for variances are shown. These figures can be presented in a simple way and are not complicated by the inclusion of fixed costs or obscured by the over-recovery or under-recovery of fixed overheads.

To the works manager is given a statement of his marginal costs of production compared with his standard marginal costs, and a schedule of his fixed charges, compared with the budget for these charges which he assisted to draw up as a matter of policy.

I suggest that to each official facts are presented which he can control, facts on which he has had a lot to say in the original fixing of the standards. They are presented in two different ways. Standards are compared with actuals for marginal costs and the budget is compared with the original budget for fixed costs. That is the simplest way of presenting the facts.

The sales manager receives similar information relating to selling activities, according to territories and types of product. He is able to see the contribution made by each area and product. Then he can compare his actual fixed costs with his budget costs.

General management, too, is given the results in two sections and is able to compare marginal costs with standards in total and in detail, and the reasons for variations are stated simply and clearly. Further, the fixed costs of the business are compared with the budget and it is very easy for the cost accountant to indicate why these results were obtained. It is correspondingly easy for management to take any desirable and possible action to bring about the necessary changes.

* *Marginal Costing: A New Tool for Management. The Accountant*, June 25th, 1955, page 716.

In each case, care should be taken to see that the man who will be responsible for working to the standards and budgets assists in their compilation and ultimately agrees that they are fair and reasonable and are capable of achievement in practice. If this is done the right spirit is created and since only those figures for which he is directly responsible are submitted to him, much useless argument is avoided.

The point has been made by the orthodox cost accountant that there is no such thing as 'fixeds' and 'variables'. A cost accountant said to me once, "I can change things like that", and he snapped his fingers very decisively. But I suggest that that man was confusing diagnosis with prescription. He recognised something as fixed and had then proceeded to take action to make it variable. In management decisions we have to recognise that. We have to distinguish clearly between diagnosis and prescription.

I have included here a paragraph on increase in fixed overheads because they are not fixed for all time. They are fixed at the moment.

In considering the problems up to this stage, it has always been recognised that facilities have been available for the course of action suggested and, consequently, the marginal cost of a product or process has been of prime importance.

However, in the routine operation of the technique of marginal costing, a careful segregation of variable and fixed overheads will have been made. If the system has been in operation for a number of years, great accuracy in the division will most probably have been achieved. If standard marginal costs are set up and a practical system of budgetary control for the fixed overheads has been established, management is able to see clearly the effect of any course of action.

Additional Fixed Costs

When it is considered necessary to incur additional fixed overheads of any description, the fixed overhead budget should be recast in the light of the changes envisaged for a period of three or possibly five years. This will show clearly the additional fixed costs which are likely to be incurred by the course of action envisaged.

These additional fixed costs are incurred to do more (or better) work. From the standard marginal costs of the additional product or products, after consideration has been given to improvement in the standards because of the increased or improved facilities, the additional contribution is shown for each year. If the contribution minus additional fixed costs gives a reasonable return on the capital employed, the expansion is worthwhile.

This line of thought must necessarily be followed, whatever system of management information is being used. The important point is, however, that with a system of marginal costing the maximum amount of information is available for management at all times.

I should like to finish by giving you what I feel to be the most important uses of marginal costing and, in part, I am repeating.

Within a business marginal costing has several definite contributions to make towards the solution of present-day problems ; firstly, in presenting information to management at all levels. To the shop foreman there are given figures which he can influence by his action, the marginal or out-of-pocket costs. These can be presented in a simple way and are not complicated by the inclusion of fixed or policy costs, or obscured by the over-recovery or under-recovery of fixed costs.

Secondly, marginal costing enables management to formulate quick yet accurate decisions on matters of policy ; whether to make or to buy ; whether to manufacture by this method or by that method ; whether to produce this product or that product. And remember that the technique can be used for products as well as machines.

Thirdly, it enables management to make decisions on both long-term and short-term policy, since they are well informed of the position "as is", and are clearly guided by the costs and budgets regarding the effect of any action taken.

Fourthly, it enables management to achieve the maximum net profit during a period, by concentrating upon obtaining the maximum contribution per unit of the element of cost in short supply. In this connection, by focusing attention on the key factor of production, it ensures the most economic working of the business taking into account all factors.

Fifthly, in industries in which by-products arise, by its use the cost accountant is able to illustrate clearly the most economic method of dealing with a by-product.

Sixthly, if market research methods are sufficiently reliable so that it is possible to estimate fairly accurately the volume of sales at varying price levels, it can be used for price fixing purposes to give the maximum contribution.

Lastly, in times of trade depression — and I deliberately put this last — it can be used to indicate to management the lowest price at which a sale can be made to recover out-of-pocket costs only. This aspect of the subject has been stressed so much that some cost accountants have regarded it as being the main, if not the only, object of marginal costing. The cost accountant who has operated such a system over the past 10 years will certainly state that the first four contributions mentioned are much more important and will probably express the view that the fourth has been most profitable.

In my own experience, I have used marginal costing for what I term 'picking the plums' and ignoring the sour grapes. That is why I stress the fourth point. I want to repeat that. The use of marginal costing "enables management to achieve the maximum net profit during a period, by concentrating upon obtaining the maximum contribution per unit of the element of cost in short supply. In this connection, by focusing attention on the key factor of production, it ensures the most economic working of the business taking into account all factors."

SCHEDULE C.

	PRODUCT "A"		PRODUCT "B"		TOTAL	
	£	%	£	%	£	%
Sales	3000	100	1000	100	4000	100
Cost of goods sold	2000	66.7	800	80	2800	70
Contribution	1000	33.3	200	20	1200	30
Fixed Charges	750	25	—	—	750	18.8
Net Profit	250	8.3	200	20	450	11.2

SCHEDULE D.

	PRODUCT "A"		PRODUCT "B"		TOTAL	
	£	%	£	%	£	%
Sales	3000	100	1000	100	4000	100
Cost of Goods sold	2000	66.7	800	80	2800	70
Contribution	1000	33.3	200	20	1200	30
Fixed Charges	562	18.7	188	18.8	750	18.8
Net Profits	438	14.6	12	1.2	450	11.2

SCHEDULE E.

	PRODUCT "A"		PRODUCT "B"		TOTAL	
	£	%	£	%	£	%
Sales	3000	100	500	100	3500	100
Cost of goods sold	2000	66.7	400	80	2400	68.6
Contribution	1000	33.3	100	20	1100	31.4
Fixed Charges	643	21.4	107	21.4	750	21.4
Net Profit	357	11.9	Loss 7	Loss 1.4	350	10.0

Appendix B

"MARGINAL COST"

Comparison of same job done

(a) on hand press
(b) on power press

Hand Press					Power Press	
3	gross		Production per hour		6	gross
4d.	per gross		Material Cost		4d.	per gross
6d.	,, ,,		Piece Work Price		4d.	,, ,,
3d.	,, ,,	(50%)	Full Overheads	(150%)	6d.	,, ,,
1/1	,, ,,		Total Cost		1/2	,, ,,
1/3	,, ,,		Selling Price		1/3	,, ,,
2d.	,, ,,		Apparent Net Profit		1d.	,, ,,
2d.	,, ,,	($33\frac{1}{3}$%)	Marginal Overheads	(100%)	4d.	,, ,,
1/-	,, ,,		Marginal Cost		1/-	,, ,,
1/3	,, ,,		Selling Price		1/3	,, ,,
3d.	,, ,,		"Contribution"		3d.	,, ,,
3 x 3d. = 9d.			"Contribution per hour"		6 x 3d. = 1/6d.	

METAL CLEANING AND FINISHING BY THE AIRLESS ABRASIVE BLASTING PROCESS*

by F. W. PEDROTTY,

Manager of Application Engineering,

American Wheelabrator & Equipment Corporation.

ABOUT 75 years ago, General Tilghman, of Philadelphia, was awarded patents on the use of compressed air to force sand through the orifice of a nozzle. In subsequent years, many improvements were made in this process, and the "sand-blast" method, as it was most commonly referred to, became a valuable production tool — much faster and more efficient than prior methods of using wire brushes and plain tumblers, especially in high production quantities.

In airless blasting, the abrasive is hurled centrifugally upon the work by means of one or more rotating bladed wheels which are strategically mounted to get the best abrasive coverage of the surfaces to be cleaned (see Fig. 1). The relatively high efficiency obtained is due primarily to the greatly decreased power requirements as the result of eliminating compressed air. As an example of this saving, a standard $19\frac{1}{2}''$ diameter $\times$ $2\frac{1}{2}''$ wide airless blast wheel, powered by a 15 h.p. motor, is capable of throwing upward of 300 lb. of abrasive per minute. To throw the same amount of abrasive at the same velocity, it would require five $\frac{3}{8}''$ nozzles and a 190 h.p. compressor to supply the air and maintain the pressure.

Industrial Applications

The following are some of the principal current applications of the airless abrasive blasting process for metal cleaning and finishing :-

1. *Cleaning Castings.* Removing loose and burnt-in sand and scale from ferrous and non-ferrous castings of all sizes and shapes, including the most complicated castings having difficult cores and deep pockets and recesses such as cylinder blocks.

2. *Removing Scale from Forgings.* Airless blasting offers important advantages over pickling in the cleaning of forgings. By eliminating the use of acid and relying entirely upon mechanical action to remove scale and other surface impurities, many of the defects inherent with pickling are overcome. No pitting, blistering or embrittlement occurs, and the resulting surface has a uniform matt finish that provides a good base for subsequent polishing, plating or painting operations, and an even surface for cold rolling or further machining.

3. *Removing Heat-Treat Scale.* By the proper selection of abrasives, it is possible to remove heat-treat scale even in cases where close tolerances must be attained, for example, in the cleaning of scale from carbon and high-speed drills, taps, cutters and reamers. At one prominent manufacturing plant, this process has eliminated tumbling of parts for removing scale, with such advantages resulting as: higher production ; greatly improved surface appearance ; and subsequent grinding time reduced due to the thoroughness with which all surface scale was removed.

4. *Cleaning Weldments.* Welding spatter and flux on fabricated welded assemblies are unsightly and naturally detract from the appearance of the finished product. Its removal by the common methods of wire brushing, grinding or chiseling is costly and laborious. These facts have led to the widespread adoption of airless blasting by the weldment industry.

The uniform blast coverage and economical high speed cleaning of the process cause welded areas to be spotlessly cleaned with a very short blast exposure. Even complicated weldments are completely cleaned

* *Presented at the 22nd Annual Meeting of the American Society of Tool Engineers, and reproduced by kind permission of the Society.*

in a few minutes' time. At one company, an airless blast machine and two operators handle the same production in one-half the time formerly required with eight chippers, grinders and wire brush men.

5. *Preparing Surfaces for Final Finishing.* The etched surface produced by the scouring action of thousands of tiny abrasive particles provides a perfect anchor for bonding the final finish. The thorough cleaning the surface receives assures the removal of every trace of rust, old paint, scale, dirt, and other foreign materials which might accelerate corrosion and promote blistering of the finish. The result is a tight bond between the coating and the parent metal surface. Airless blasting is widely used to obtain the surface required for proper rubberising, galvanising, painting, plating, bonding glass to metal, metallising, etc.

6. *Cleaning and Finishing of Die Castings.* Airless blasting has three major applications in the die casting field. Its use may be justified in any one of these categories and in many cases the process may show benefits in all three categories on the same type of part. These three applications are: (1) preparation of the surface for better adhesion of subsequent coatings; (2) removal of small, thin flash and burrs; and (3) elimination of the symptoms of porosity.

7. *Cleaning Required in Reconditioning Operations.* The field of reconditioning has grown into a major industry with parts such as auto parts, steel drums, compressed gas cylinders, floor maintenance machines, water and gas meters, valves and fittings, etc., being rebuilt or reconditioned and placed into service again. In each case thorough removal of all foreign materials such as old paint, rust, dirt, scale, etc., is the first requirement of proper reconditioning. The high-speed airless abrasive blast scours away every trace of foreign matter in only a few minutes, cleaning the used parts so thoroughly they look like new.

In addition to the above listed applications, this method is used for such diversified operations as removing flash and fins from plastic mouldings, deburring, providing an etch on steel mill reduction rolls, descaling of steel sheet and strip, shot peening to increase the strength of stressed parts, roughening the surface of leather basketball carcasses, etc.

Types and Sizes of Ferrous Abrasives

One of the important factors in solving a specific cleaning or finishing problem is the selection of the right abrasive for the job.

Prior to the introduction of airless blast cleaning, the most common abrasive in general use was silica sand. Although it is still being used today in comparatively limited quantities, its use was rapidly reduced with the introduction of metallic abrasives. The main reasons for the unpopularity of sand in the abrasive blasting field are:-

1. rapid breakdown rate: after three to five passes through the blast cycle it is converted to dust;

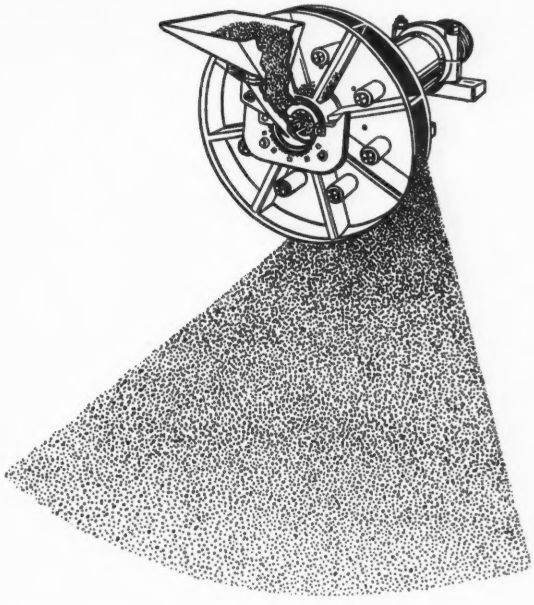


Fig. 1. Phantom view of Wheelabrator airless type projector.

2. the silica present creates a health hazard to the operating personnel;
3. the wear on vital parts of the equipment is extremely high, as compared to metallic abrasives, creating costly maintenance problems.

The first metallic abrasive put into general use was *cast chilled iron.* The usable life of this abrasive is approximately five times that of sand, and it reduces the maintenance of the equipment about 50%. The second metallic abrasive to become popular in blast cleaning applications was *heat-treated chilled iron or malleable abrasive.* The life of this abrasive is approximately two-and-a-half times that of regular chilled iron and further enhances the life of wearable parts, thus reducing maintenance costs. The most recent developments in metallic abrasives are *cast steel and cut wire shot.* Both of these abrasives will outlast regular cast iron shot at least five to one, and cut maintenance costs on the equipment up to 200%.

According to available records, the most common pure steel shot now in use is the cast steel shot, which is an electric furnace product fully heat-treated and drawn. Because of its extreme toughness, cast steel abrasive is only available in short form. Up to this time, no practical device has been developed capable of crushing or breaking it into the form of angular grit.

Cut wire abrasive is manufactured by cutting various types and sizes of steel wire into lengths equal to their diameter, forming pellets. Because of the sharp edges on these pellets when first charged into the machine as compared to cast steel shot, a longer

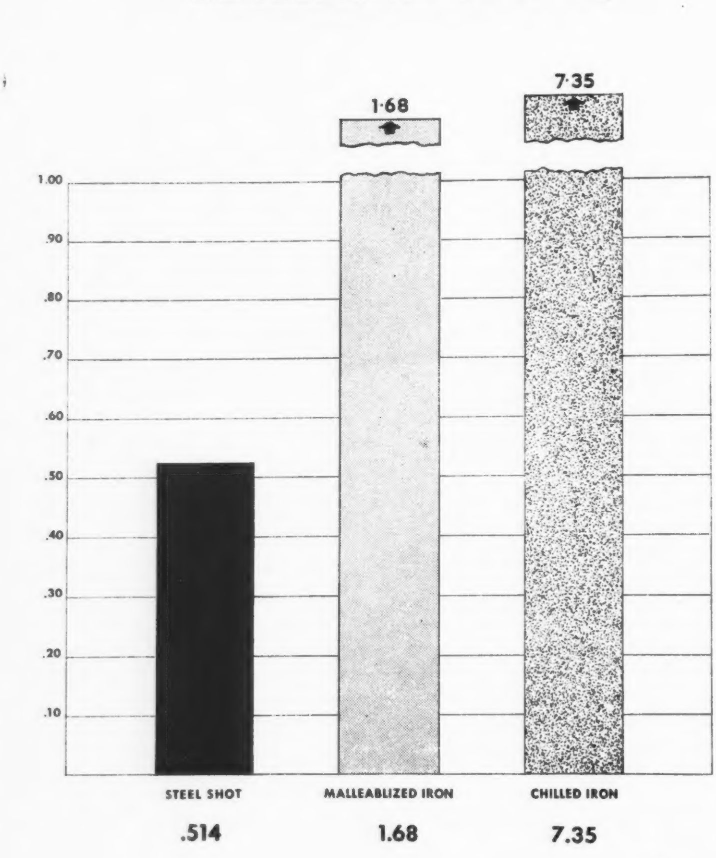


Fig. 2. Cost per life cycle — steel shot versus malleablised iron versus chilled iron.

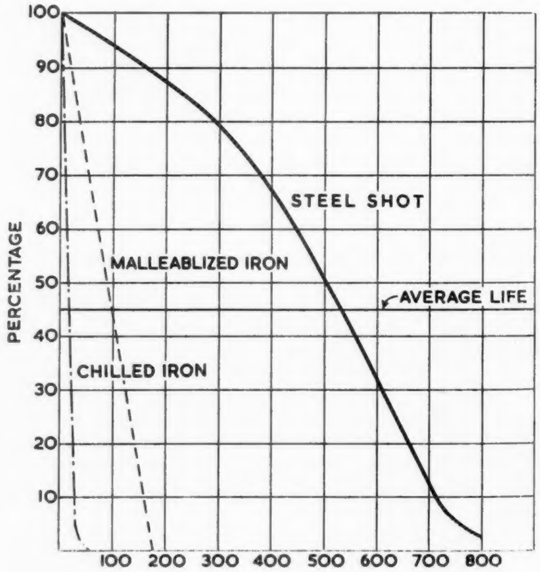


Fig. 3. Average life of steel shot versus malleablised iron versus chilled iron. Test is carried out until 45% of the shot has not passed through the next smaller sized screen.

"breaking-in" period is required before it is stabilised into operating round shot.

There are two forms of cast metallic abrasive in general use. One is called "shot"; the other is "grit". All cast abrasive is first made in the shot form and is fairly uniformly round. Grit is angular in form and is manufactured by crushing the round shot. Currently, grit is available only in the cast iron and malleable type abrasive, but not in some of the finer sizes in the latter type.

The comparison of life and cost between the three main abrasives, steel, malleable and cast iron, can best be shown by charts made from breakdown tests (see Figs. 2 and 3). Such tests are made in a standard shot tester, which is a small wheel unit throwing the abrasive at high velocity against a hardened target. The test is carried out until 55% of the shot is broken down or passes through the next smaller sized screen.

Today all abrasive manufacturers conform to definite screen sizes established by the Society of Automotive Engineers. Certain tolerances are permitted, but in the shot sizes, a minimum of 65% to 85% must be retained on the screen designated for each respective size. S.A.E. has established 13 sizes in shot. The smallest is S-70. In this size, a minimum of 65% of the shot must be retained on a No. 80 screen (having an opening of 0.0070"). The largest size is S-1320. With this, a minimum of 85% of the shot must be retained on a No. 6 screen (having an opening of 0.132").

In the grits, there are 12 sizes ranging from the finest, G-325, with a minimum of 20% retained on a No. 325 screen (having an opening of 0.0017"), to the largest, G-10, where a minimum of 80% is retained on a No. 10 screen (with an opening of 0.0787").

Obviously, the degree of roughness or fineness of the finish obtained is dependent upon the size of abrasive selected. Generally, shot gives a peened finish, and grit a matt finish. To attempt to specify in this discussion the type and size of abrasive best suited for the many applications for which abrasive blast equipment is being used today would not only be difficult, but impractical. One reason is the many variables involved, such as the degree of hardness of metal and the scale to be removed; the individual taste or opinion of the ultimate user of the abrasive as to which type of finish is best suited for their particular product; the constant changes and improvements being made in the metallurgy of metals.

Perhaps the most important reason is the continued research and development being made in producing improved new types and quality of abrasives. For instance, acceptable cleaning and finishes are being obtained with the new cast steel shot on metal products more economically, and sometimes faster, than could formerly be accomplished with metallic grits only. Because of the foregoing, equipment manufacturers have complete demonstration departments available to the trade, where tests can be conducted to predetermine the abrasive and equipment best suited for the job. Prospective users of blast cleaning equipment should avail themselves of these facilities to eliminate all guesswork and headaches before the equipment is installed.

Non-Ferrous and Non-Metallic Abrasives

In addition to the ferrous metal abrasives, there are two non-ferrous metal abrasives being used; namely, copper and zinc. These abrasives are relatively new and are not yet being used very extensively. Currently their application is mostly confined to cleaning and some cases of deburring brass, aluminium and zinc die castings.

In the non-metallic abrasives, there are on the market:-

1. crushed apricot pits, walnut and pecan shells;
2. ground corn cobs;
3. rice hulls.

In the first type, the apricot pits have proved to be the most popular. They are being used quite extensively in airless-blast equipment for deflashing in the plastic industry. Also, on certain types of aluminium castings, very light fins are being removed successfully. The second and third types are not too practical for airless-blast applications because of their relative lightness and softness. They are normally used in airblast equipment for removing light scales, such as carbon from automotive and aircraft motor parts, in motor testing laboratories.

Standard Airless-Blast Equipment

To meet the demand for airless-blast equipment, manufacturers have designed many work-handling methods for presenting various metal products to the abrasive blast for high production, mechanised cleaning and finishing.

Figs. 4 and 5 show the Tumblast or barrel type machine. This was the first type of machine to which the airless-blast unit was adapted in 1933, and is still one of the most popular and versatile machines on the market today. The diagrammatic view (Fig. 5) shows the endless apron conveyor principle used for handling the work. The phantom view (Fig. 4) shows all the important features of the complete machine. The wheel unit throws a fan-shaped pattern of blast across the work as the forward travel of the conveyor tumbles the work and exposes all surfaces to the blast action. The spent abrasive falls by gravity through perforations to a screw conveyor, which feeds the abrasive through a rotary screen to remove any large contaminants removed from the work. From here, the bucket elevator carries the abrasive to an overhead abrasive separator, where the abrasive is "washed" pneumatically to remove any sand or unusable fine abrasive before delivering the clean abrasive to the storage hopper. This automatic recycling and cleaning of the abrasive is very important to the efficient performance of blast cleaning equipment. The door can be easily opened for inspection and the work can be unloaded by simply reversing the apron conveyor. This type of machine is available in various sizes ranging from one cu. ft. to 63 cu. ft. load capacity.

The previously described machine is usually referred to as a batch or intermittent type. To meet the

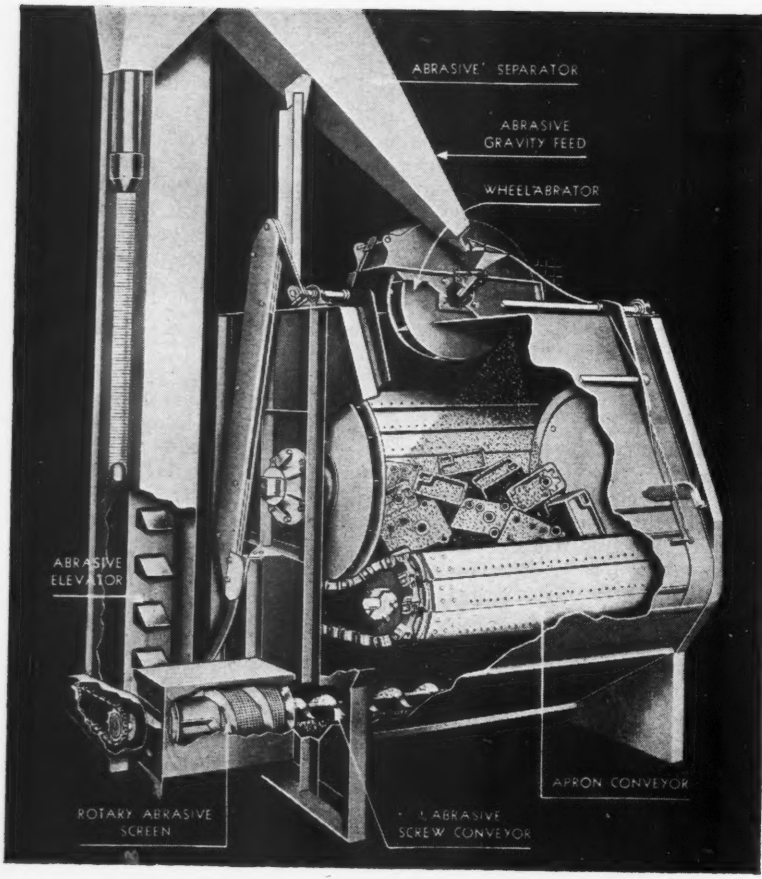


Fig. 4. Phantom view of barrel-type machine, showing the important features.

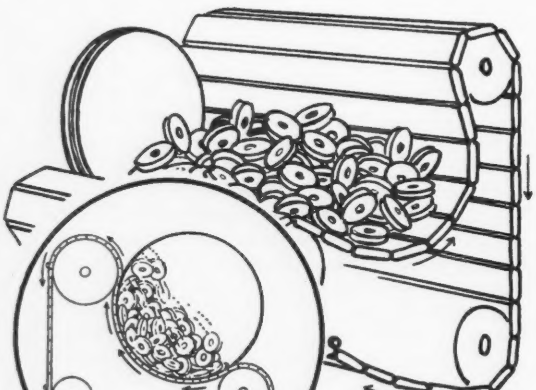


Fig. 5. Diagrammatic view of barrel-type machine, showing the endless apron conveyor principle used for handling the work.

demands of very large producers of fairly uniform-sized parts, such as the automotive and pipe fitting manufacturer, a continuous barrel-type machine was built as shown in Fig. 6. This machine also employs the endless apron conveyor principle, but the flow of work is continuous and lends itself to the highly conveyorised producing plants where interruption of the work travel through various operations is undesirable.

For work that does not lend itself to the tumbling action, various types of table machines have been developed. These include plain table type (Fig. 7), multi-table type (Fig. 8), and swing-table type (Fig. 9).

Various sizes of these tables are in use, the most popular being the multi-table and swing-table types, because the entire area of each table rotates under the blast pattern many times as it passes through the machine, thereby achieving faster cleaning results.

Special Airless-Blasting Equipment

Whereas the previously described machines are usually referred to as "standard" type, much work has been done on the development of "special" machines designed to meet high production of large or intricate parts which are difficult to clean in the "standard" machine.

A Monorail cabinet type machine (Fig. 10) employs the overhead conveyor principle for carrying work through the blast zone. Multiple airless blast wheels from two to eight, depending upon the type of work to be cleaned, are mounted on the vertical side walls in varying positions to give the best coverage of areas to be cleaned. There are many variations in the monorail line travel through the cabinet. It may be single-pass, double-pass or triple-pass, depending on individual requirements. In the most common arrangement, the work is carried on spinner hooks which index and revolve in front of each blast wheel for a predetermined period of time. Work may be hung on the hooks in single or multiple numbers. Very high production is obtained on such typical work as cylinder blocks and heads, crankshafts, camshafts, rear axle housing and shafts, soil pipes and fittings, bath-tubs and sanitary ware, miscellaneous iron and steel castings, forging and fabricated parts.

A relatively new development is the car-type room. This airless blast machine was designed to meet the demand to eliminate or greatly reduce the need of air blast rooms where very large work is cleaned with

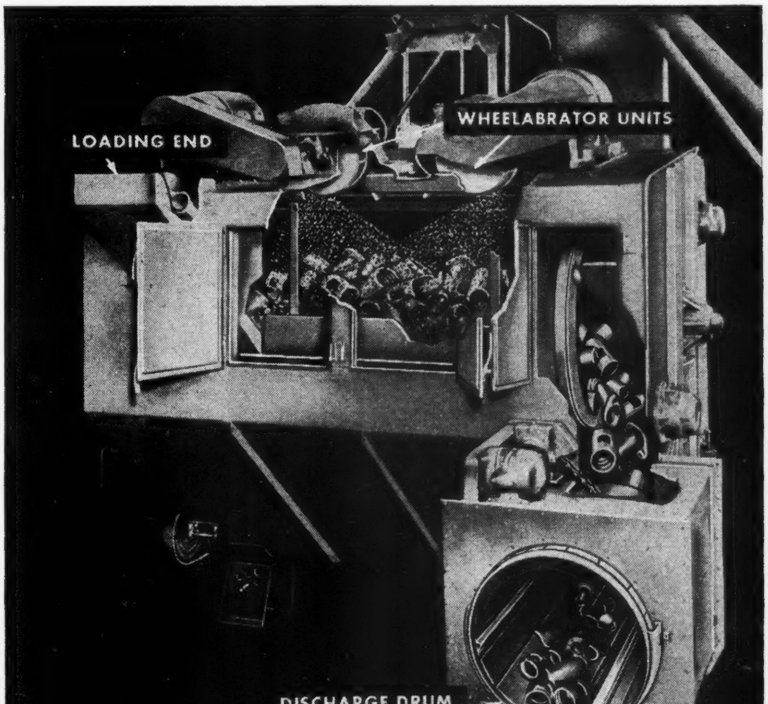


Fig. 6. Continuous barrel-type machine for airless abrasive blasting fairly uniform-sized parts.

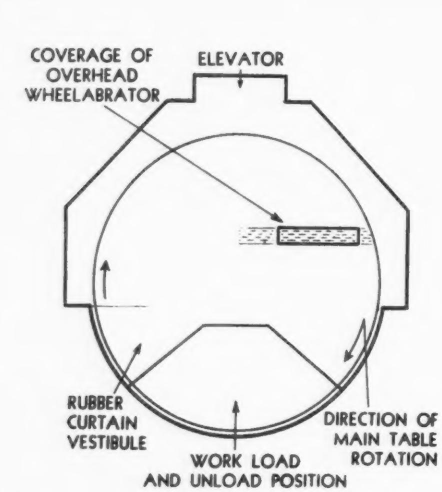


Fig. 7. Diagrammatic view of operating principle of a single work table blast machine.

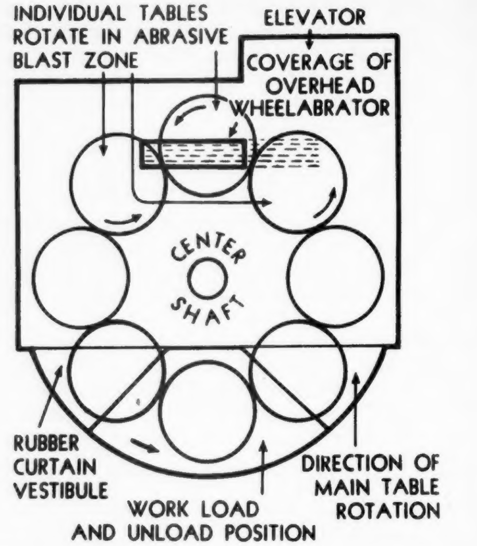


Fig. 8. Diagrammatic view of operating principle of a multi-table blast machine.

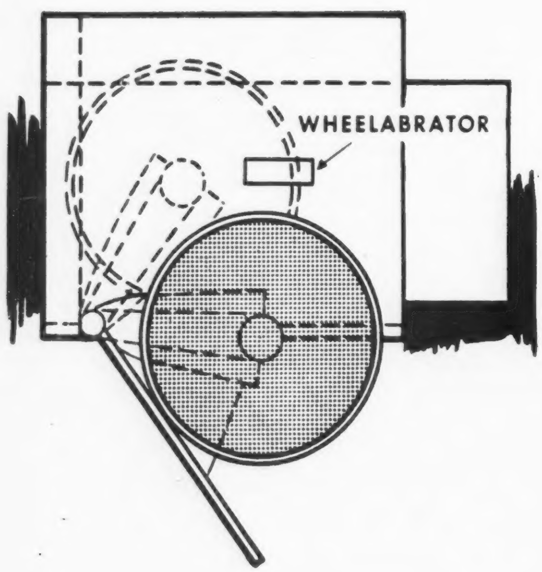


Fig. 9. Diagrammatic view of operating principle of a swing table-type blast machine. Shaded portion shows table in open and loading position; dotted lines show table in closed and operating position.

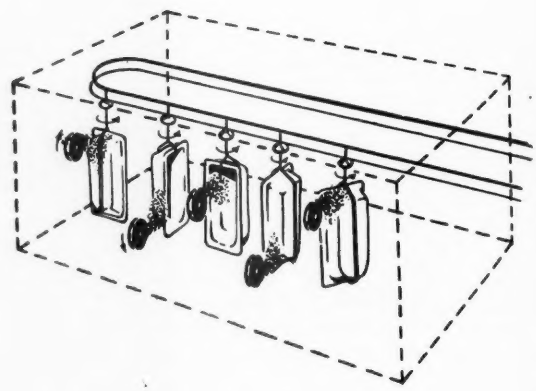


Fig. 10 Diagrammatic view of a monorail cabinet-type of airless blasting cleaning machine. Fine airless blast units are utilised at different levels for throwing abrasive upon the work to be cleaned.

manually operated blast nozzles. Car-type rooms are in use for cleaning work weighing up to 35 tons. Multiple airless blast wheel units, from two to nine in number, are common to this type of equipment. The work is rotated on tables. In work weights up to 10 tons, the table can be mounted on the car that carries the work into and out of the room. On work heavier than 10 tons, the table is built into the room, and the sled-type car carries the work on to the table, similar to a railroad turn-table.

The airless blast cabinet employing a skew-dished-roll conveyor (Fig. 11) is extensively used for handling cylindrical work. Such work as pipe and tubing of various diameters, gas cylinders, printers rolls, ammunition shells, etc., are being cleaned in this type of equipment in high production quantities. One or two airless blast units are normally required for this type of machine.

Several types of special airless blast machines have been developed for the metal drum reconditioners. One of the types is shown in Fig. 12. This machine is capable of removing old paint, rust and other accumulations from used 55-gallon and 30-gallon metal drums at the rate of 80 to 100 per hour. Both open and closed-end drums are adaptable to this machine. The work handling method employed is shown on the diagrammatic view.

Recent Developments

In recent years, many special airless machines have been designed for the steel mill industry for removing scale from carbon and stainless steel strip, plates and slabs and the etching of cold reduction mill rolls. Sheets are carried through the cabinet on a roller conveyor, and four airless blast wheels are employed, two above and two below, which uniformly remove scale down to the virgin metal from both sides in one pass. Similar machines are in use today employing up to 16 airless blast units.

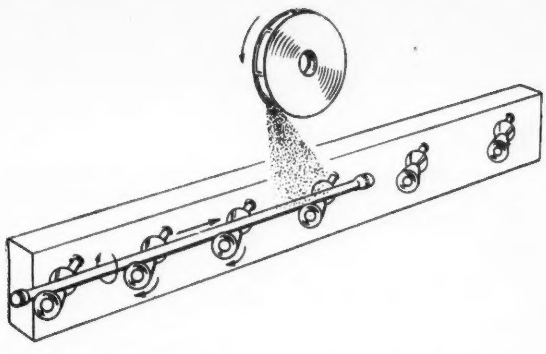


Fig. 11. A diagrammatic view of the skew-dished roller conveyor type of blast machine for carrying cylindrical objects past blasting machine.

With the development of the airless blast wheel it became economically practical to adapt the process of abrasive blasting to scores of metal cleaning and finishing problems. New work handling methods with the operator working outside a properly ventilated and carefully sealed cabinet brought about safety improvements, and the development of metallic abrasives made possible great increases in productivity with equally great decreases in the cost of operation.

Because of the complete flexibility of control over the blasting action, airless blasting is now being universally applied to all phases of the metal cleaning field. Products can be given a silvery matt or a satin finish, as desired, by the selection of the proper abrasives. Airless blast cleaning today is considered an important general purpose production tool.

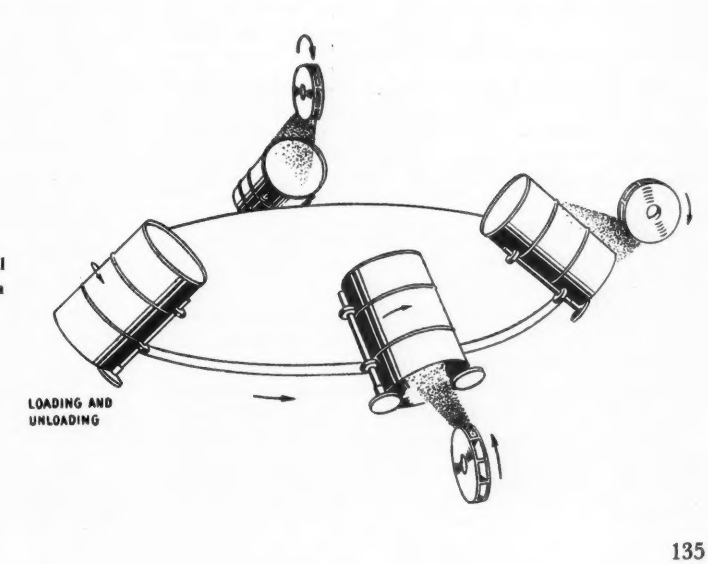


Fig. 12. Diagrammatic view of a two-wheel drum cabinet used for cleaning 55 gallon steel drums.

news of members

NEW YEAR HONOURS

The Institution records with pleasure the following awards made to members in Her Majesty the Queen's New Year Honours List:-

O.B.E.

Principal C. D. Alder, M.I.Prod.E., Cornwall Technical College, Redruth.

M.B.E.

Mr. W. H. Hopkins, A.M.I.Prod.E., Works Manager, E.M.I. Factories, Ltd., Wembley.

OBITUARY

His many friends and colleagues throughout the Institution will have been grieved to learn of the sudden death, on Christmas Day, of **Mr. Tom Fraser,** C.B.E. This news was received just as the present issue of the Journal was going to press, and a full appreciation of Mr. Fraser, who was one of the Institution's oldest and most valued members, will appear next month.

The Institution records also with great regret the death of **Mr. J. D. Frier,** Member. Prior to his retirement in 1953, Mr. Frier was Head of the Mechanical Engineering Department of the Coventry Technical College. He had served on the Institution's Joint Examination Board, as examiner and assessor, for over 10 years.

Mr. A. Bailey, Member, will be moving to Adelaide, South Australia, in March, 1957, to install, set up and manage a F.H.P. motor division for Kelvinator Australia Limited, England. Mr. Bailey transferred from Nash-Kelvinator Limited, England, in October, 1956, after being General Factory Manager of the Crewe factory for the past six years. Mr. Bailey has been a Member of the Institution for some years and was the first Chairman of the South Wales and Monmouthshire Section.

Mr. F. H. G. Lane, Member, has now concluded his contract with Messrs. Braithwaite & Co. (India) Limited, Calcutta, and has taken up an executive appointment with Messrs. Braithwaite & Company Structural Limited, London, West Bromwich and Newport.

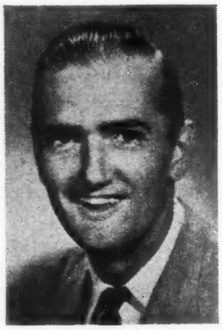
Mr. D. H. McCormack, Member, has taken up a new senior production appointment with Churchill Gear Machines Limited, Newcastle.

Mr. C. F. Rose, Member, has been appointed to the position of Production and Works Assistant with responsibility to the Chief Mechanical and Electrical Engineer and the Carriage and Wagon Engineer of the Eastern and North Eastern Regions, Doncaster.

Mr. J. G. Crofts, Graduate, is now Service Manager of Messrs. Burn & Co. Limited, Howrah, Calcutta, has been appointed Deputy General Manager.

Mr. R. L. Aston, Associate Member, has recently been promoted to Senior Lecturer in Production Engineering at the College of Technology, Cardiff. Mr. Aston serves on the South Wales Section Committee.

Mr. N. H. Bradbury, Associate Member, has relinquished his position as Lecturer in Mechanical and Electrical Engineering at the County Technical College, Kings Lynn, to take up an appointment as Head of the Engineering and Mining Department at the Bishop Auckland Technical College, Co. Durham.



Mr. R. A. Farman, Associate Member, of Lever Brothers (India) Limited — which recently changed its name to Hindustan Lever Limited — joined his present Company as Methods Study Manager in 1952. Previously he was a Senior Industrial Engineer with the Parent Company, Lever Brothers Limited, Port Sunlight. His present assignment, as head of the Methods Study Department, is to advise on productivity in the Company's six factories located in various parts of India.

Mr. K. J. B. Dunn, Associate Member, is now Chief Planning Engineer to British European Airways Maintenance Base at London Airport with the title of Planning Superintendent. His previous position was Planning Superintendent at the Renfrew Maintenance Base.

Mr. A. E. Kirtom, Associate Member, is now Assistant Works Manager of Mauritius Railways.

Mr. E. C. Lucking, Associate Member, has relinquished his position as Personnel Officer with the Glacier Metal Company, and has joined the Northern Electric Company Limited, in Montreal, as an Engineer.

Mr. G. Sharp, Associate Member, has taken up the appointment of Chief Inspector with the Brush Electrical Engineering Company Limited, Loughborough.

Mr. H. J. C. Weighell, Associate Member, has joined The Sperry Gyroscope Co. Ltd., London, as Production Methods Superintendent.

Mr. J. M. Barber, Graduate, has recently taken up an appointment as Production Manager at Test Equipment, Ltd., Crawley.

Mr. J. G. Crofts, Graduate, is now Service Manager at Triplejay Equipment (Rhod.) (Pvt.) Limited, Salisbury, Southern Rhodesia.

Mr. D. Jamie, Graduate, has recently taken up an appointment as Development Engineer at Messrs. Richard Thomas & Baldwins, Griffithstown, Mon.

Mr. N. A. Martin, Graduate, has recently joined the Lockheed Hydraulic Brake Company as a trainee Method Study Engineer at their Leamington Works.

Mr. S. A. Onions, Graduate, has relinquished his position as Senior Planning Engineer with Messrs. Wilmot Breeden Limited, Bridgwater, and has taken up an appointment as a Senior Planning Engineer with Bristol Aircraft Limited, Filton.

Mr. K. Perkins, Graduate, has now been demobilised from the Royal Air Force and has taken up an appointment with the English Electric Company Limited, Rugby, in the Manufacturing Engineers Department.

Mr. D. G. Slatter, Graduate, has relinquished his appointment with Messrs. Chubb & Sons Lock & Safe Company, and has taken up a position with Hoover (Washing Machines) Limited, Merthyr Tydfil, as a Planning Engineer.

EDUCATION DISCUSSION GROUP
MIDLAND CENTRE
REPORT OF ACTIVITIES, 1956

Chairman:
W. L. JACKSON, A.M.I.Prod.E.,
Chance Technical College, Smethwick.

Hon. Secretary:
N. WARD, B.Sc., A.M.I.Prod.E., A.M.I.Mech.E.,
Handsworth Technical College, Birmingham.

THE first meeting of the year was held on the 11th February, and a Paper was presented by Mr. T. B. Worth, M.I.Mech.E., M.I.Prod.E., A.M.I.E.E., a former Education Officer of the Institution and at present in charge of Production Engineering in the Mechanical Engineering Department of the College of Technology, Birmingham. His subject was "Production Engineering or Industrial Engineering?" and his material was largely obtained during his visit to America. He put forward many ideas which were well received and provided the basis for a lively discussion; many questions were posed, and answered by Mr. Worth with clarity and humour to the satisfaction of all present.

The second meeting, on 16th June, was addressed by Mr. K. J. Hume, B.Sc., M.I.Mech.E., M.I.Prod.E., Chief Education Officer of The Dowty Group of Companies. His subject was "The Practical Training of the Production Engineer." This provided so much interest and discussion that the outcome was to continue it at a later date and the third meeting was held on 20th October with Mr. Hume again opening the discussion on the same subject.

In the meantime, Mr. Hume very kindly arranged for members of the Group to visit the works of Dowty Equipment Ltd., at Arle Court, Cheltenham, and to see at first hand the training scheme conducted there. This visit took place on the afternoon of 23rd July, and proved both enjoyable and instructive, the weather being ideal for visiting a modern works in such beautiful surroundings. Arrangements had also been made for the members to visit the Engineering Department of the North Gloucestershire Technical College at Cheltenham during the morning of the same day, by the kind permission of the Principal.

The next meeting of the Group will be held at 10 a.m. on 9th February, 1957, at the Engineering Centre, Exchange Buildings, Stephenson Place, Birmingham (at the New Street end of the New Street Station), and Mr. F. Beach, A.M.I.Mech.E., A.M.I.Prod.E., will open the discussion on "Examination Papers — with special reference to Production Engineering."

Future meetings are planned to take place on June 22nd and October 19th at the same place and timed to commence at 10 a.m.

In accordance with the broad terms of reference which govern the Group's activities, the Chairman, on behalf of the present members of the Group, heartily invites to these meetings any member of the Institution from industry or from educational institutions in the Midland area who is interested in the education of the Production Engineer. It is hoped thereby to provide, through discussion, new ideas and an appreciation of the difficulties involved in such education, together with methods of overcoming them, in order that the training and teaching may be of the highest possible standard.

The Hon. Secretary will be pleased to send additional information to any interested members who will contact him.

Members are reminded that copies of the Library Catalogue may be obtained from the Librarian, price 2/6d., plus 4d. postage (price to non-members, 10/-, plus 4d. postage).

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"PNEUMATIC GAUGING TECHNIQUE IN ITS APPLICATION TO DIMENSIONAL MEASUREMENT"

(concluded from page 120)

visible at a glance. An account of this apparatus is being prepared for publication.

The usefulness of the pneumatic gauge as a fiducial indicator in certain types of measurement should not be overlooked. For example, in combination with a large thimble micrometer fitted with a non-rotating anvil, the air-gauge can be used fiducially to measure the displacements of a surface. The magnification of the gauge could be made, say, 1,000, so that errors of setting the micrometer would be eliminated. With a good micrometer, the periodic errors should not exceed 0.000 02 in. and the progressive error could be determined in advance to a similar accuracy and allowed for if necessary. The movements of the surface over a range up to 1 in. could thus be measured with an accuracy of about $\pm 0.000\ 03$ in. with relatively simple apparatus.

Acknowledgments

The Author wishes to acknowledge the suggestions he has received from his colleagues Mr. I. G. Morgan, M.A., and Mr. A. J. Garratt, M.B.E., B.Sc., during many discussions on the theoretical and practical aspects of pneumatic gauging.

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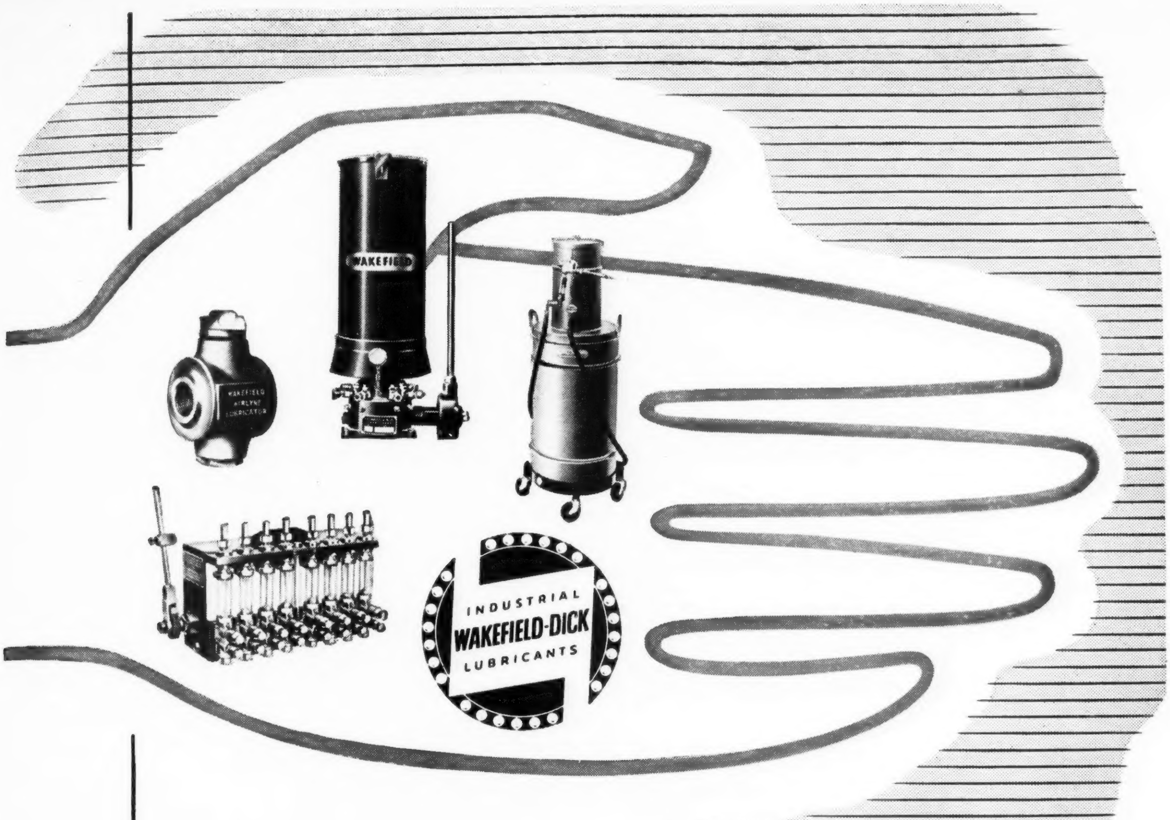
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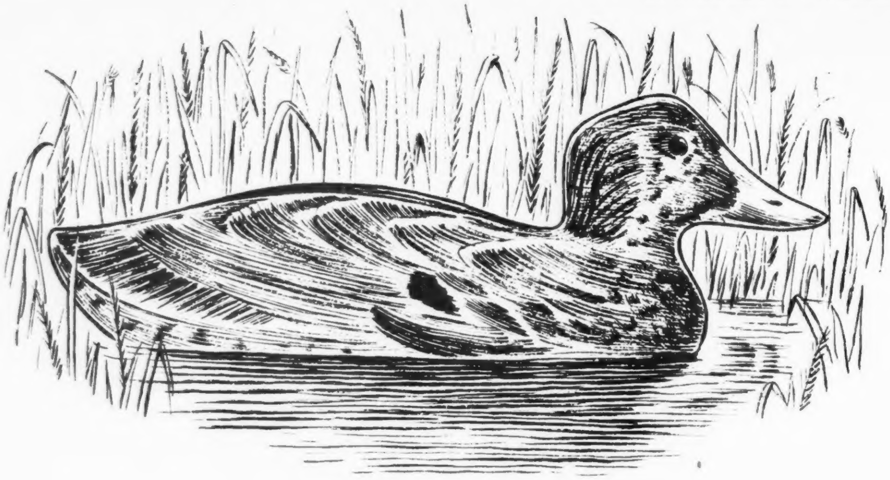

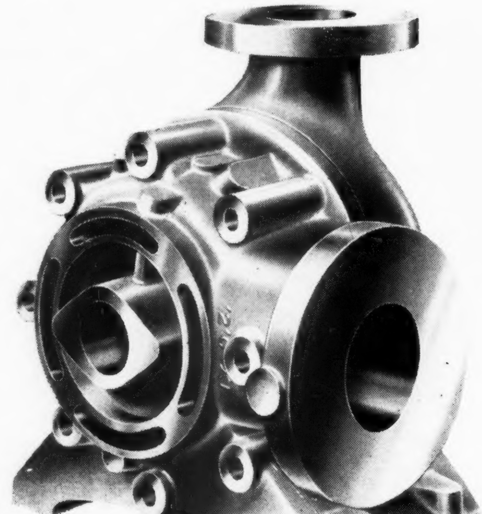

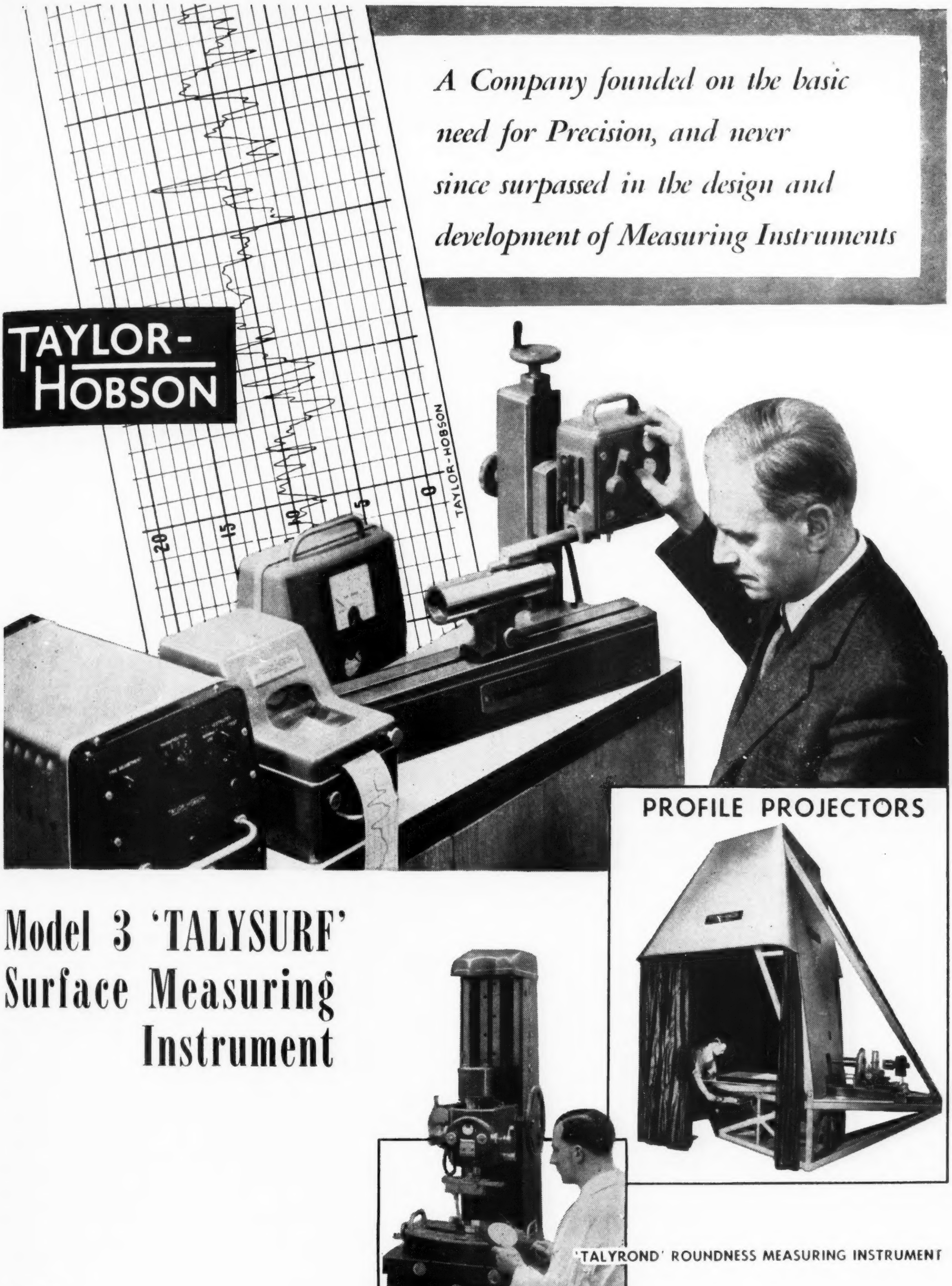
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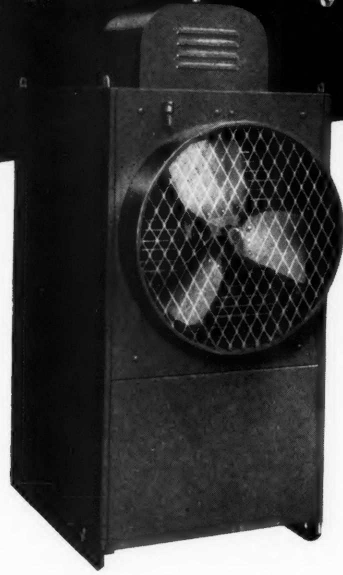


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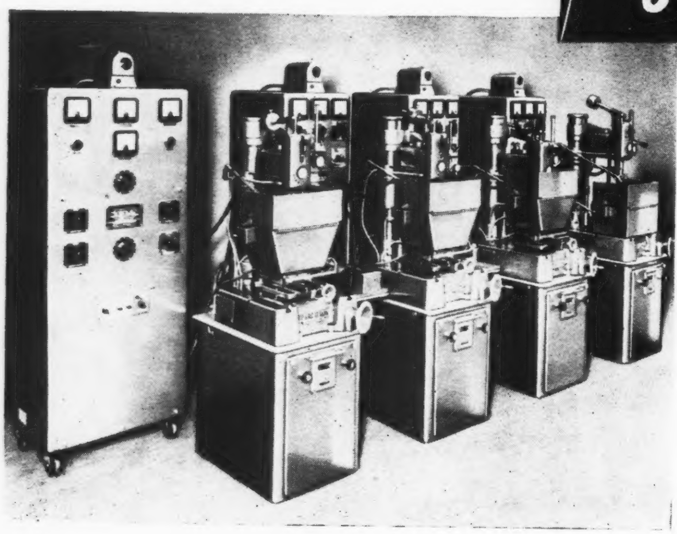

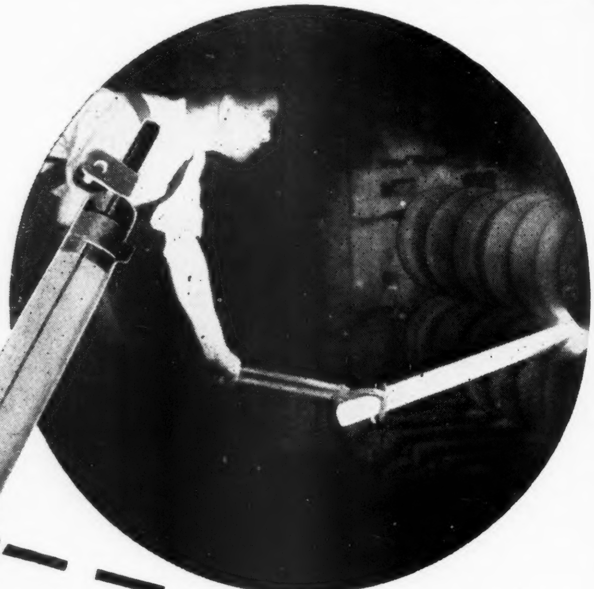

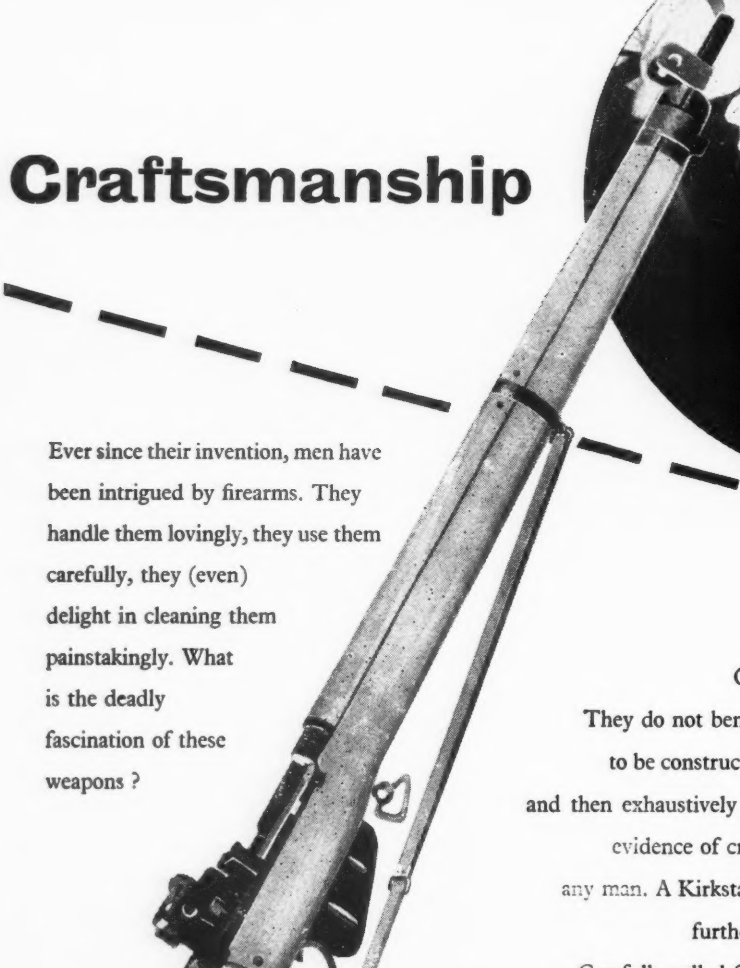

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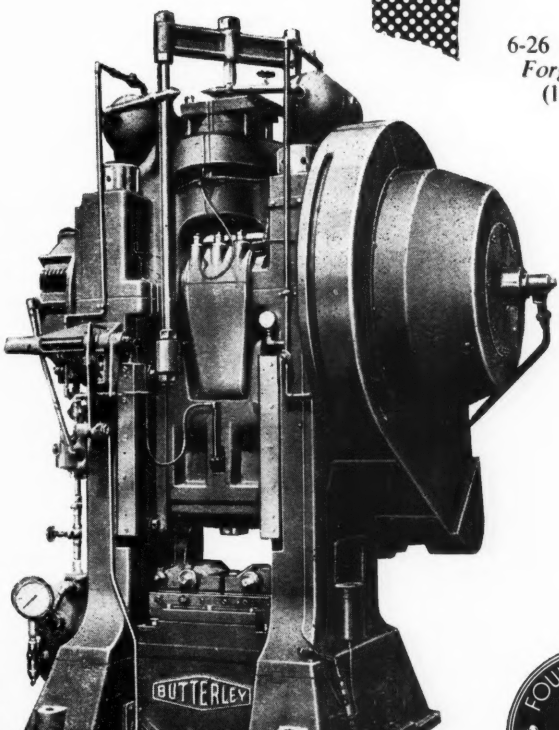

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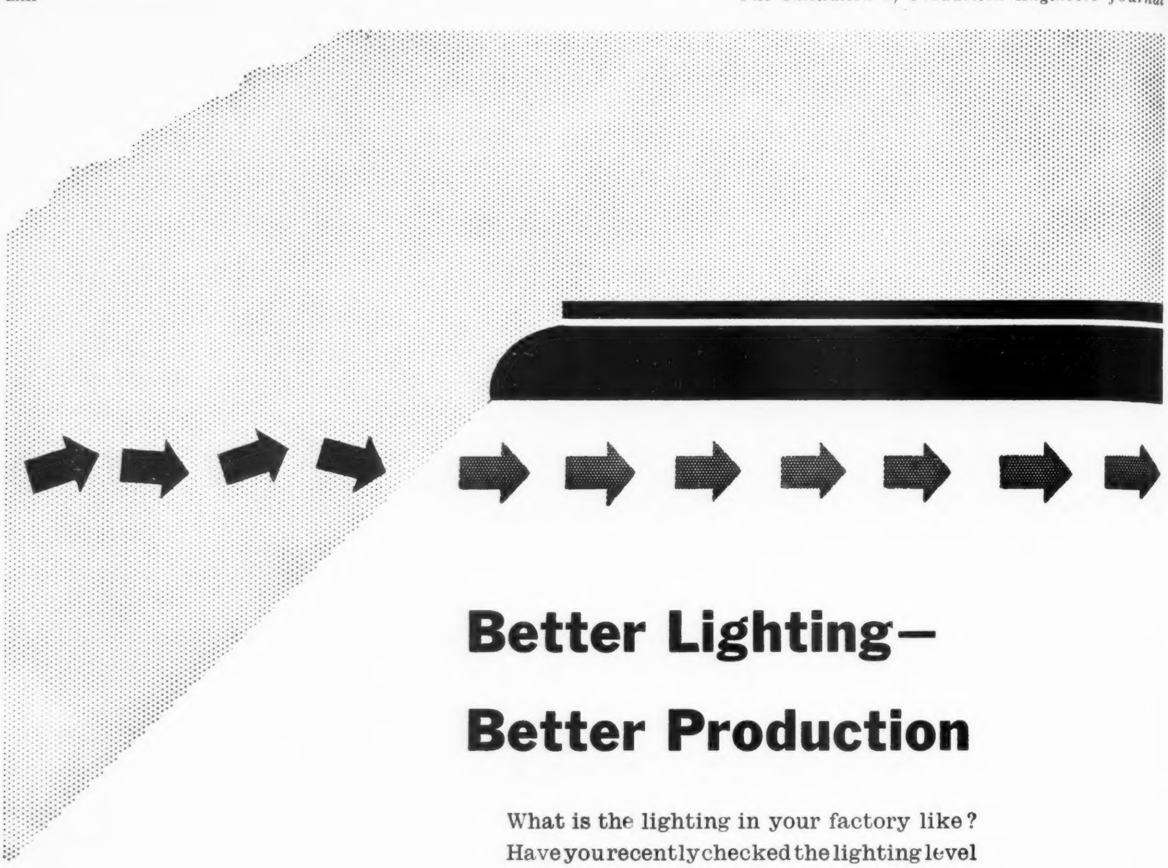

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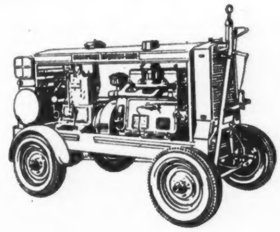

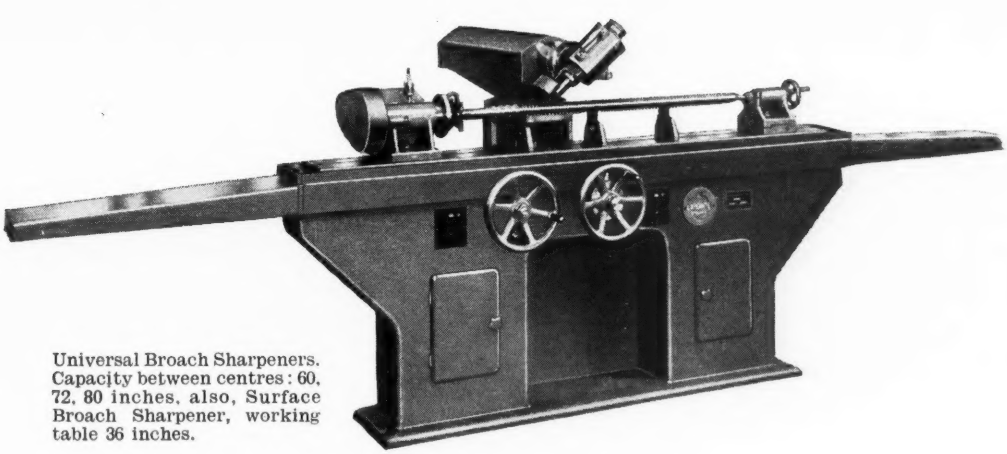

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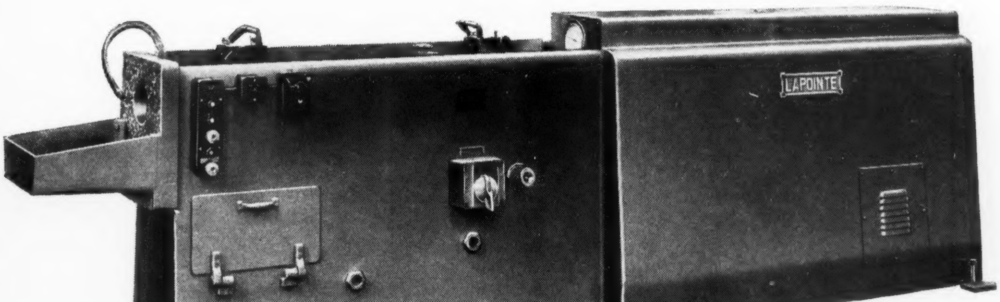

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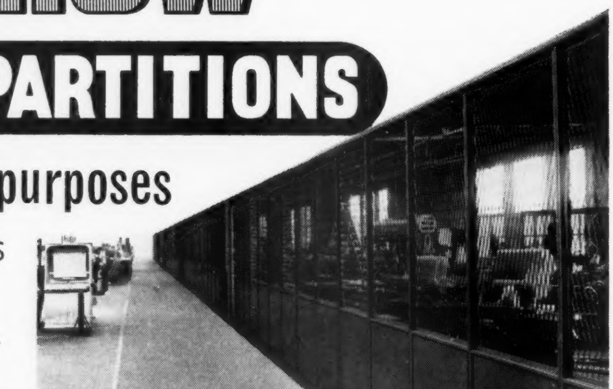

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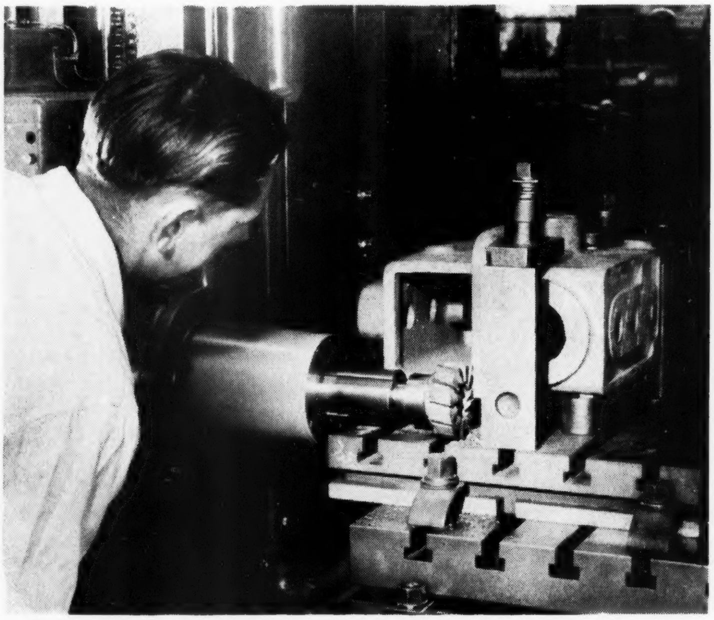

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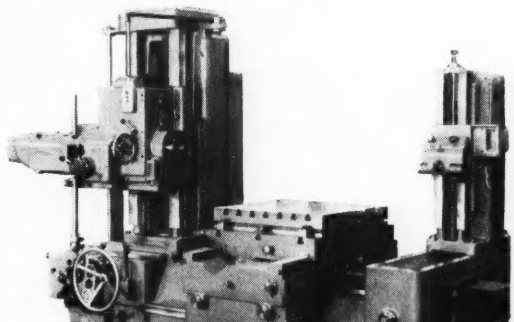

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